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STUDIES ON INTELLIGENT MANAGEMENT FOR STABLE INFORMATION NETWORK SYSTEMS

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STUDIES
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INTELLIGENT MANAGEMENT FOR STABLE INFORMATION NETWORK SYSTEMS

by
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PREFACE

In a complex interconnected network system, the basic problem is to effectively manage the stability of communication channel shared by many users, who need high quality and efficiency of services. In order to comply with these demands, various multiple access communication protocols and management mechanisms have been proposed, developed and standardized. In a typical network system consisting of a large number of networking machines and equipments, contention-based protocols have been well known and commonly utilized as the effective multiple access protocol. However, using contention-based protocols, it happens that two or more users attempt to transmit their transmitting packets or messages on a shared communication channel in the short period. At that time, most of packets or messages usually have been destroyed and lost in the 'collision' or 'conflict' period, and most of them should be retransmitted. Some of very frequent retransmissions may cause the instability of the network, and this phenomena is well known as the bistability problem.

Therefore, in order to overcome this instability problem of the contention-based protocols, Tsybakov and Capetanakis proposed an excellent protocols independently. Their protocols are based on tree algorithms or tree-based collision resolution algorithms, they use a tree structure in resolving a collision based on the feedback information on the physical level of network layers. It is notable that tree-based collision resolution algorithms stabilize a contention-based communication system and guarantee the maximum throughput of the channel.

However, these kinds of protocols only utilize the feedback information in the lowest level of communication layers, it is too difficult to perform the global stability of the interconnected network systems. Especially, in the environment of networks using various protocols, many equipments in the networks exchange the monitoring information of their own status. It is very important to gather and collect high level information in order to analyze and perform the global network systems.

Therefore, the major objective of this dissertation is to propose and evaluate several new protocols in order to stabilize networks using multi level protocols. In order to transmit various kinds of messages such as data, voice, or graphic images with different requirements for transmission, we focus on the stability control in both of local and wide area networks based on the lower and higher level feedback information.

First, in chapter 2, we propose a CSMA/CD protocol employing the blocked access tree collision resolution algorithm as its back-off algorithm, and evaluate its performance. In chapter 3, we propose DTA-MR protocol and investigate the priority mechanisms using the information from the sequence of transmitting time and the delay of transmitting time.

Second, in chapter 4, in order to derive rules for the traffic distribution and patterns in the interconnected networks, we extend attribute-oriented induction algorithm for knowledge discovery in dynamic environments. We can discover three kinds of intelligent rules, such as characteristic rule, stable rule and evolution rule, it is possible to manage and stabilize network systems globally by derived rules. In chapter 5, we use the technology of active database to automatically control the network systems using high level protocol information, and we also propose the sampling technique based on the occurrences of composite events in the management information base. We also evaluate the memory cost performance of the sampling method based on composite events detection in several contexts.

Finally, the author would like to hope that the research in this thesis will be helpful for further study in this field.

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Chapter 1

Introduction

1.1 Communication System

We will consider the communication networks which consists of many distributed terminals to communicate complex and multifarious packets over a shared communication medium. When we focus on one network which is separated by bridges, routers or other network equipments, we have several types of multiple access protocols to send only a single packet over one channel at one transmission time. It is possible to share the capacity of the channel efficiently by these multiple access protocols, such as controlled-access protocols or contention-based protocols[Toba77].

However, there are many problems and difficulties to implement these protocols over communication channels which have quite different characteristics in several view points. For example, when we design the network systems, we have to consider the number of server/client stations, the volume of traffic for point to point or multicast/broadcast communication, or the length of propagation delay time and others. In order to resolve these problems, many protocols have been proposed and evaluated by many researchers, and they provide high throughput and low message delay in one networks[Toba80].

In this thesis, we will direct our attention to the intelligent management of stability in interconnected networks, which is shown in Fig. 1.1, based on several communication protocols [Kawa88a, Kawa92a, Kawa92b, Kawa95b, Kawa96b].

1.2 Protocols in Communication Networks

When we design the interconnected communication system including multiple networks, we have to use many equipments which adopt various protocols in the view point of local stability. Moreover, the current information systems tend to utilize each communication medium for transmitting multifarious messages such as *text*, *voice*, or *graphic images*. In these complex situations, the types of packetized messages would vary in length and generation interval, and the requirements for transmission of each kind of messages would be different. Thus, in addition to realizing the stability of communication channels, it is important to develop transmission protocols which can reflect the requirements as well as features of the packetized

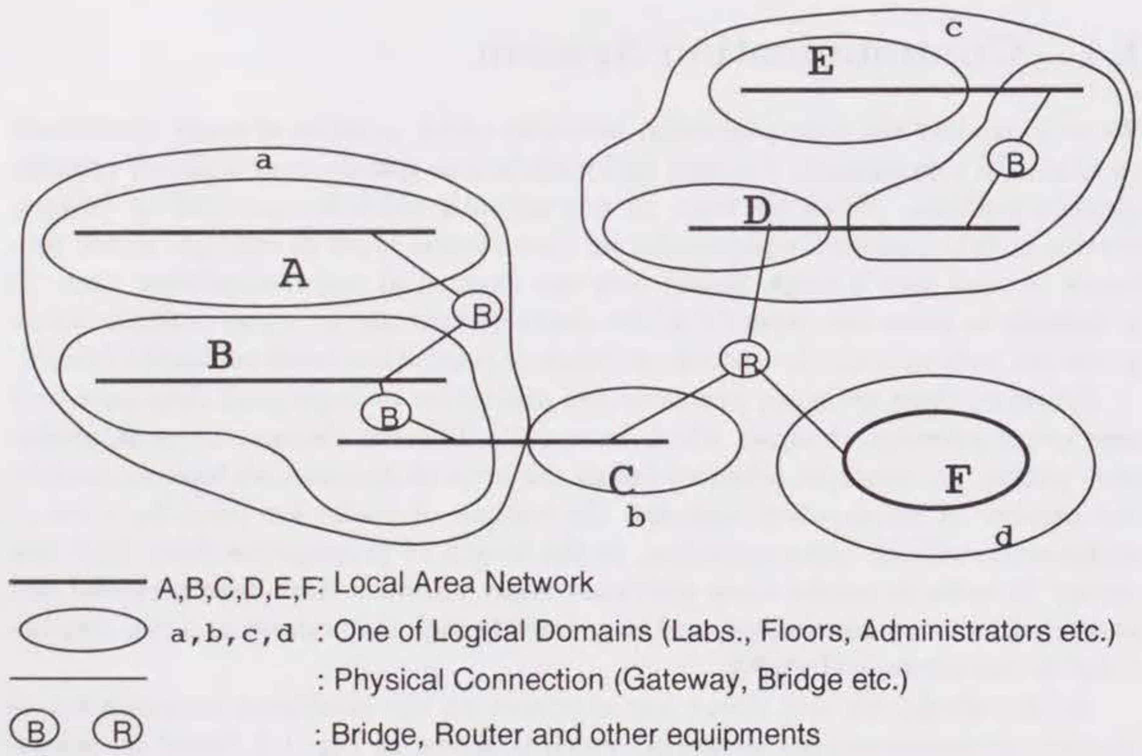

Figure 1.1: Topology of networks and equipments.

messages of multifarious information media.

In this section, we explain the structures or hierarchy of various types of communication protocols in interconnected networks.

1.2.1 Protocol hierarchies

First, in order to reduce the complexity of network design, communication networks should be organized as a series of layers[Tane81]. For example, the reference model of Open System Interconnection (OSI) model is designed by International standards organization(ISO) in a highly sophisticated way. The reference model consists of the following seven layers, specifying particular network functions such as addressing, flow control, error control, encapsulation, message transfer, and others in Fig. 1.2.

1. *Physical layer* is defined by the electrical, mechanical, and other specifications in order to activate and deactivate the physical channel between network equipments.

2. *Data link layer* provides reliable transmission of data, which is concerned with physical addressing, network topology, line discipline, error notification of frames and flow control.

3. *Network layer* offers a complex routing mechanism in order to choose and connect the path between two equipments, that may be in geographically different segments.

4. *Transport layer* provides reliable service for virtual circuits, transport fault detection and recovery, and information flow control.

5. *Session layer* provides sessions between applications, class of service and exception reporting, data exchange is based on dialogue between two or more presentation entities.

6. *Presentation layer* has the ability of translation between several data representation formats, it guarantees that information transmitted by the application layer will be readable by the application layer of other system.

7. *Application layer* is the closest layer to the individual user, network resources for the intended communication of two programs on different machines are identified and established.

According to the basic principles of OSI, it is easy to implement various protocols independently on each layer, thus there exists many protocols to transmit raw bits, packets or messages over a communication channel. At present, many researcher have been developing various protocols to transmit packets over one shared communication channel effectively.

There are many authors who have proposed and extended the mechanism of various multiple access protocols, and evaluated the characteristics of the protocols[Tane81, Oie86]. According to several researches, we are able to classify these protocols into two classes, controlled-access protocol and contention-based protocol.

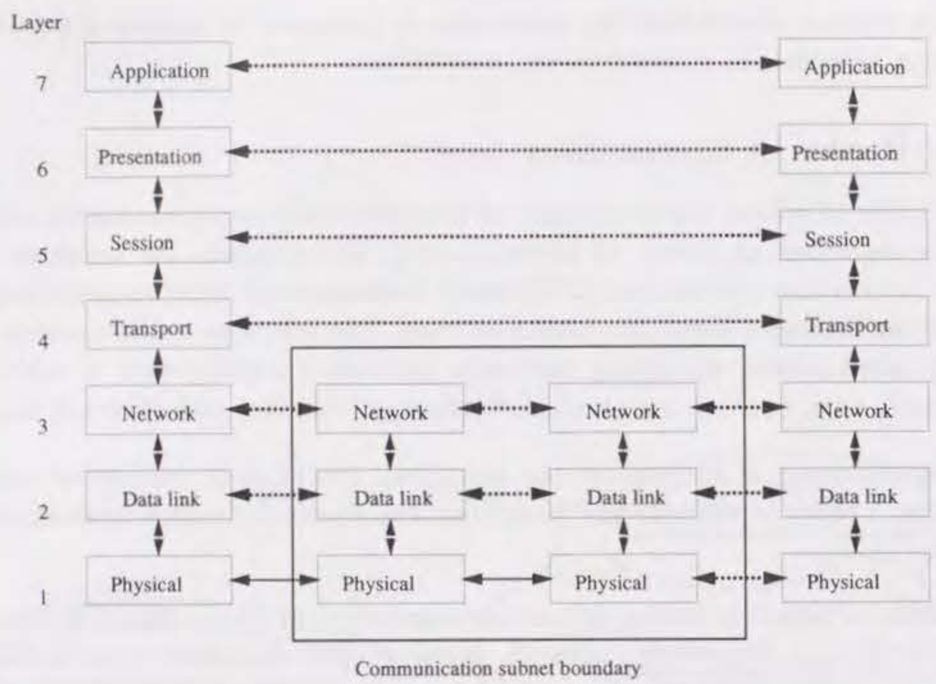

Figure 1.2: The network architecture based on the ISO OSI reference model.

1.2.2 Controlled-access protocol

Generally speaking, controlled-access protocols have the following classes, distributed terminals have to wait for their transmission time under the control of the central station or server.

- **Fixed channel allocation protocols**

  The resource of common channel is divided into the several width by the several measures, most famous protocols are Time division multiple access (TDMA) and Frequency division multiple access (FDMA)[Toba80].

  TDMA assigns fixed channel time slot to each station, and it is possible to transmit one packet in one time segment without overlapping with other stations. On the other hand, FDMA assigns frequency slot and bandwidth to each station.

- **Demand-adaptive protocols**

  By demand-adaptive protocols, it is possible to allocate the resource of the channel flexibly. Distributed stations are controlled by the central controller in polling or probing schemes, the mechanism of token passing scheme is also one of polling schemes[Toba76].

  In reservation schemes, a user have to reserve the channel in order to transmit messages, the reservation are proceeded on the two types of channels; i.e., commonly used communication channel and request channel.

1.2.3 Contention-based protocols

For constructing decentralized systems, the development of fully-distributed and effective communication protocols is one of most important research issues. Random multiple-access communication systems with the contention type channel have the feature to easily implement distributed protocols. The contention-based protocols are divided into the following two classes, ALOHA type and tree-based protocols.

- **ALOHA type protocols**

  The basic idea is very simple, just let their users transmit whenever they have packets to be sent[Abra70, Klei75b]. The mechanism of CSMA/CD is the standard and commonly used protocols in the lowest communication layer of local area networks (LANs)[ANSI802.3].

However, several well-known papers including [Fayo77] and [Haye78] demonstrated the inherent channel instability of the typical ALOHA type random access scheme in the absence of external control when the number of transmitters is large. It has been pointed out in many papers that the channel stability of CSMA/CD scheme with back-off algorithms inherently suffers, if the channel traffic becomes too heavy. (See, e.g., refs. [Medi83, Good88])) Collisions reduce the system performance remarkably and often make the channel state very instable. Therefore, the most important issue in the conventional research and developments in this field has been the resolution of conflicts for efficient use of the common communication medium.

- **Tree-based protocols**

  A highly effective innovation in random access schemes for slotted communication channel systems was introduced independently by Capetanakis [Cape79b, Cape79a] and, Tsybakov and Mikhailov [Tsyb78] with the concept of a collision resolution algorithm. Their proposed protocols have been shown to excel in channel stability (see, e.g., [Cape79a, Cape79b, Muro85]), and many algorithms have been investigated by numerous authors under various distributed environments of communication systems (see, e.g., [Haye78, Tsyb80a, Tsyb80b, Pipp81, Tsyb82, Moll83, Mera83, Oie86, Tsyb87, Tows87, Kawa88a, Poly93]).

Their proposed algorithm is often called tree type algorithm, and as the basic property the group of terminals with collided packets is divided into subgroups algorithmically, which guarantees the channel stability. It has been shown that tree type collision resolution algorithms excel in the channel stability, and many tree type algorithms have been investigated aiming at the improvement of the system performance such as throughput and delay characteristics.

Since then, many tree type algorithms have been investigated aiming at the improvement of the system performance with/without additional feedback information. (see ref. [Muro86a, Kawa88a]) Typical tree type algorithms employ one of two types of access protocols, i.e., blocked access protocol [Cape79b] and free access protocol [Math85]. In the blocked access protocol[Hofr84], new packets are transmitted in the first slot after all previous conflicts are resolved, i.e., new packets remain blocked at their respective transmitters until the current collision resolution interval terminates. On the other hand, the free access protocol permits new packets to transmit during the collision resolution interval[Mose85, Huan85]. The procedure of blocked access protocol is easier than that of free access protocol.

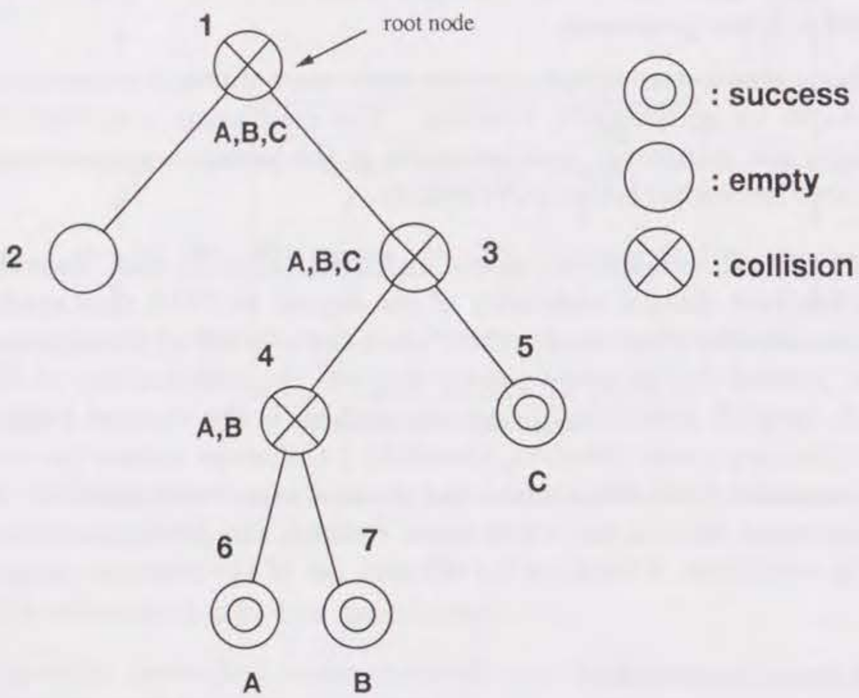

Figure 1.3: Example of a collision resolution graph for tree protocol.

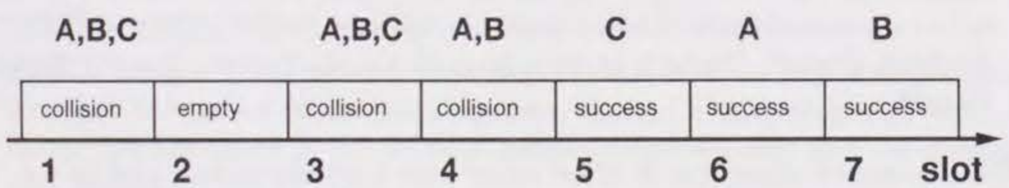

Figure 1.4: Example of collision resolution for Fig.1.3.

Moreover, several CSMA/CD schemes with tree type collision resolution algorithms have been proposed, and at least two organizations have already implemented these types of CSMA/CD protocols. The performance of these protocols has been evaluated by some authors for the case of free access scheme [Geor86, Moll83]. However, as for the CSMA/CD scheme with blocked access protocol, its detailed access protocol and performance analysis have not yet been presented.

1.3 Management Information in Communication Networks

Many networking environment including repeaters, bridges and switches has been developed to provide sufficient band width for many applications by employing the protocols in the previous section. Some of networking equipments have been designed to connect several clusters which includes different communication protocols, therefore it is very difficult to unify the features of communication protocols. However, using different protocols makes other types of instability problems in the interconnecting networks, we need much more higher level protocols to manage the stability of complex networks. In order to achieve such difficult as well as important network management, basically we have to continuously monitor the system status of different ports (stations) and layers using certain network protocols [RFC1067]. Especially, by using technique of database systems[Ullm88, McCa89], some attributes are collected by RMON (Remote network MONitoring), and then stored into Management Information Base (MIB) in Fig. 1.5, which are defined in SNMP (Simple Network Management Protocol)[Stal93].

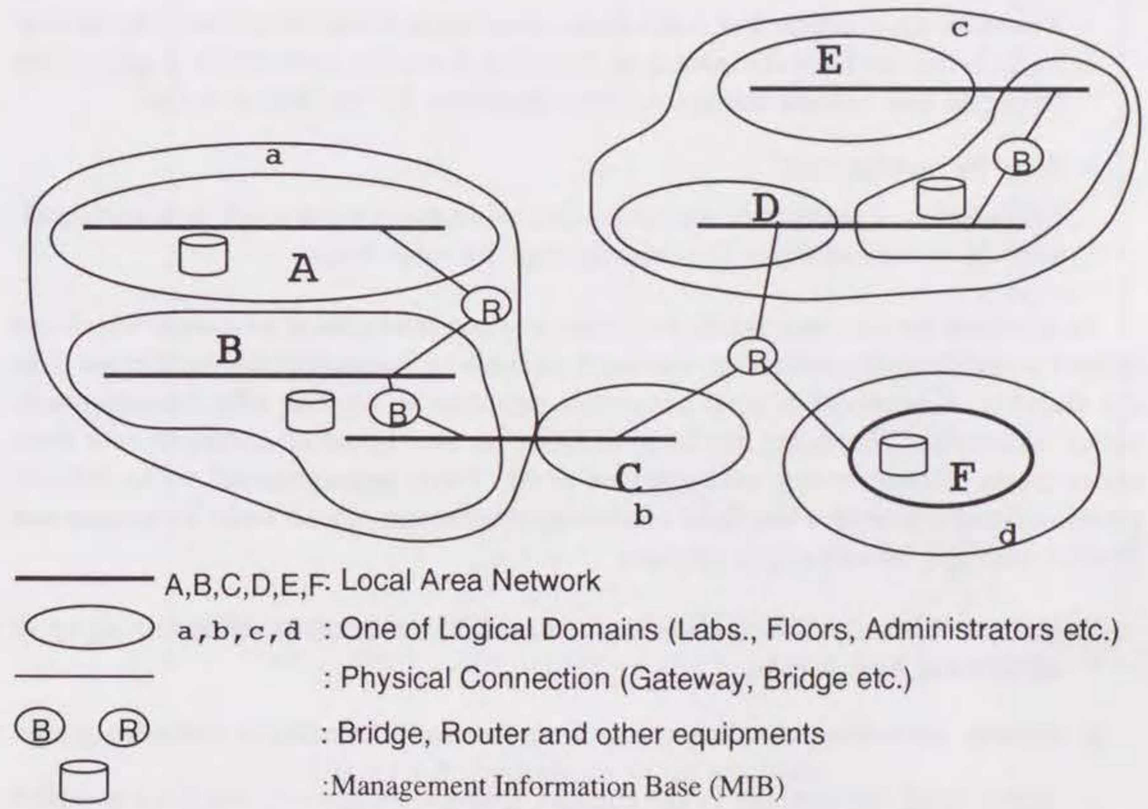

Figure 1.5: Management information base in interconnected networks.

1.3.1 Network management

In an interconnecting network, various techniques have been proposed for network management [Covo89, Gerl91, Kawa92b, Morr91, Pan91], since there are several following categories of network management problems[Stal93].

- *Performance management*

  The networks are composed of various equipments which must share the resources, it is important to improve network performance by the characteristics of several attributes values.

- *Fault management*

  When a fault happens in the network, it is important to detect the location of equipments, to reconfigure or modify the topology of networks, and to repair the failed components or to send the urgent message to administrators.

- *Accounting management*

  The network administrators have to charge or track the usage of network resources by each user or a group of users.

- *Configuration and name management*

  Networks are composed of individual equipments which have been named logically, when we have initializing or shutting down the network, it is important to decide and control the appropriate hardware by the logical name.

- *Security management*

  Information of passwords, authorization or access-control must be maintained, and the system examine the security logs by some tools.

In previous section, we explain two classes of communication protocols which use several scheduling algorithms to transmit packets or messages, we mentioned that the stability of networks is most important problem to provide effective communication channels. Therefore, we have to focus on two types of managements from above items, "Performance management" and "Fault management". The RMON protocol[Stal93] provides the data collecting mechanism, those main attributes are divided into the following nine groups:

1. *statistics*: low-level utilization and error statistics monitored by the agent of networking equipments.
2. *history*: periodical sampling values from several attributes in statistics group.
3. *alarm*: send the message to the console, if there are more or less than specified values of attributes in any sampling interval.
4. *host*: various types of traffic to and from hosts.
5. *hostTopN*: top of N hosts are reported by sorted statistics attributes.

6. *matrix*: error and utilization information are recorded in matrix form.
7. *filter*: monitor analyzes the information of packets which match a condition of filter and stores statistics into attributes.
8. *packet capture*: buffering scheme for capturing packets from one of the channels in the filter group.
9. *event*: a table of all events generated by the agent.

We have to analyze the characteristics of the above nine attributes and must define some conditions to trigger actions for network management in *alarm*. For example, we observed the channel and stored some *statistics* attribute values into MIB in Fig. 1.6, and if the abnormal values are detected by some tools, we will have the following simple alarm events which are generated by two threshold values in Fig. 1.7.

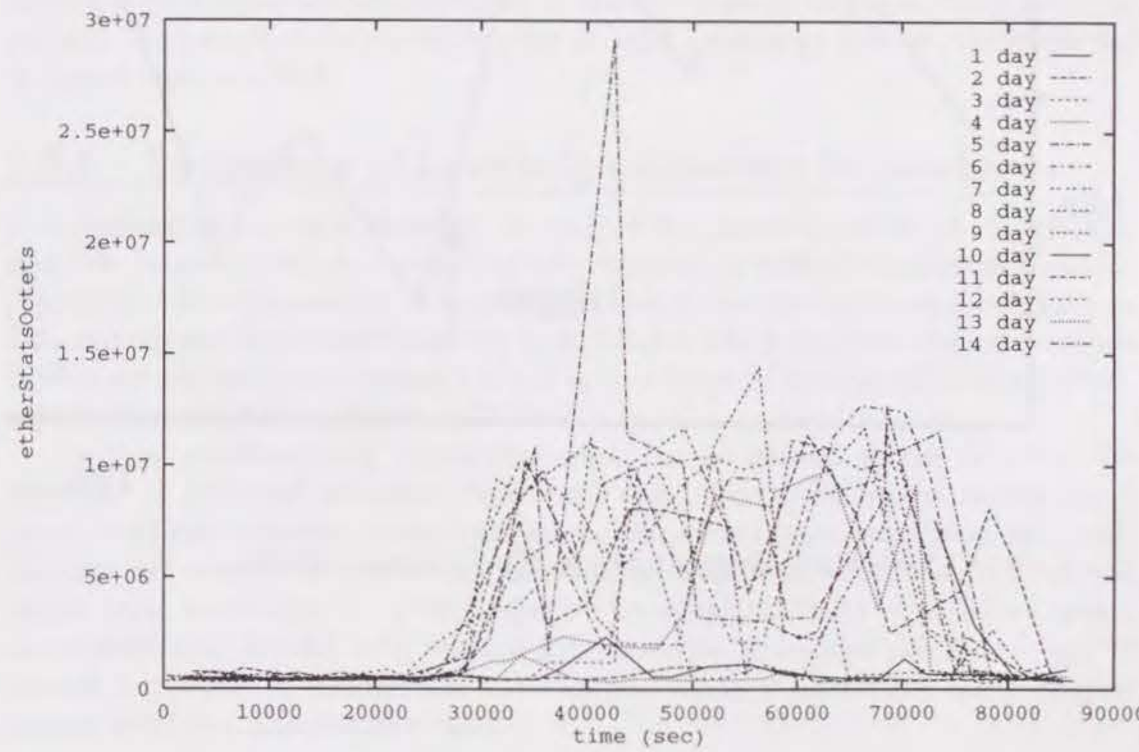

Figure 1.6: Periodicity of an attribute.

Thus, we can partially use data as information in high level layers to manage communication systems, and it is possible to control networking equipments under satisfying the global constraints and requirements of communication networks.

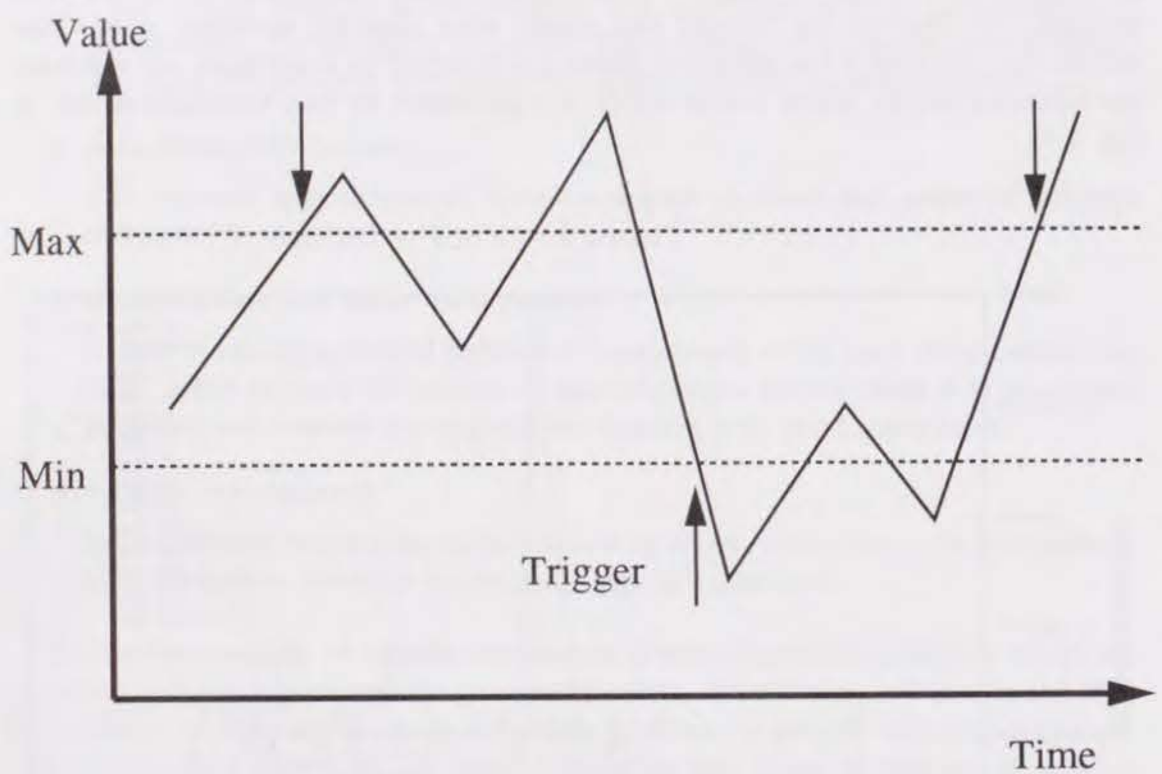

Figure 1.7: Triggering by a value of single attribute.

However, these triggers are defined by rules of events conditions, the quality of these rules strongly depends on the knowledge and experiments of network administrators. It is truly difficult to describe flexible and adaptable rules for various features and conditions of interconnecting networks.

1.3.2 High level information in management database

In such a complicated communication network, huge volume of data is generated rapidly and continuously, and stored into management database. It contains a huge amount of information, changing with time, which is a valuable resource for understanding the global and general behavior of the networking environment. However, the data generated in a dynamic networking environment are often expressed in low level primitives and in huge volumes. Therefore, the status of the network changes over time, and the difficulty of effective and stable operating of the global network system is evident. It is important to discover the useful rules and meaningful knowledge from the primitive data in the MIBs.

For example, multiple attributes may be tightly related the unstable problems in Fig. 1.8, but it is too difficult to describe sophisticated conditions with multiple attributes in *alarm*, as we shown in the previous subsection. When we try to describe the much more sophisticated conditions in order to manage interconnecting networks globally, we have to derive suitable rules or valid knowledge derived from collected or stored data into MIB.

1.3.3 Techniques of knowledge discovery in databases

It is challenging but truly necessary to analyze the general behavior of the information flow in such dynamic networking environments in order to understand and/or control the status[Kawa95a]. It is quite effective to use the new techniques, such as data mining and knowledge discovery in databases, which are the excellent methods to discover regularity and anomaly in the various kinds of databases[Piat91a, Han93, Ston93, Nish93, Hols94, Han94, VLDB95].

By most of discovering algorithms, rules can be derived as the following expression: If *left hand side* then *right hand side*. There are several categories of rules, *exact rule* allows no exceptions, *strong rule* allows some exceptions, and *probabilistic rule* relates the conditional probability. When we would like to grasp the higher level knowledge, it is very effective to adopt attribute oriented induction algorithm[Cai91, Han92] with concept generalization as background knowledge. It is most important to discover the following two kinds of interesting rules: *characteristic rules* and *classification rules*.

1. *characteristic rule:*

   Objects that belong to the concept named in the left hand side, contain properties named in the right hand side.

2. *classification rule:*

   The left hand side is a sufficient condition to classify objects as belonging to the concept named in the right hand side.

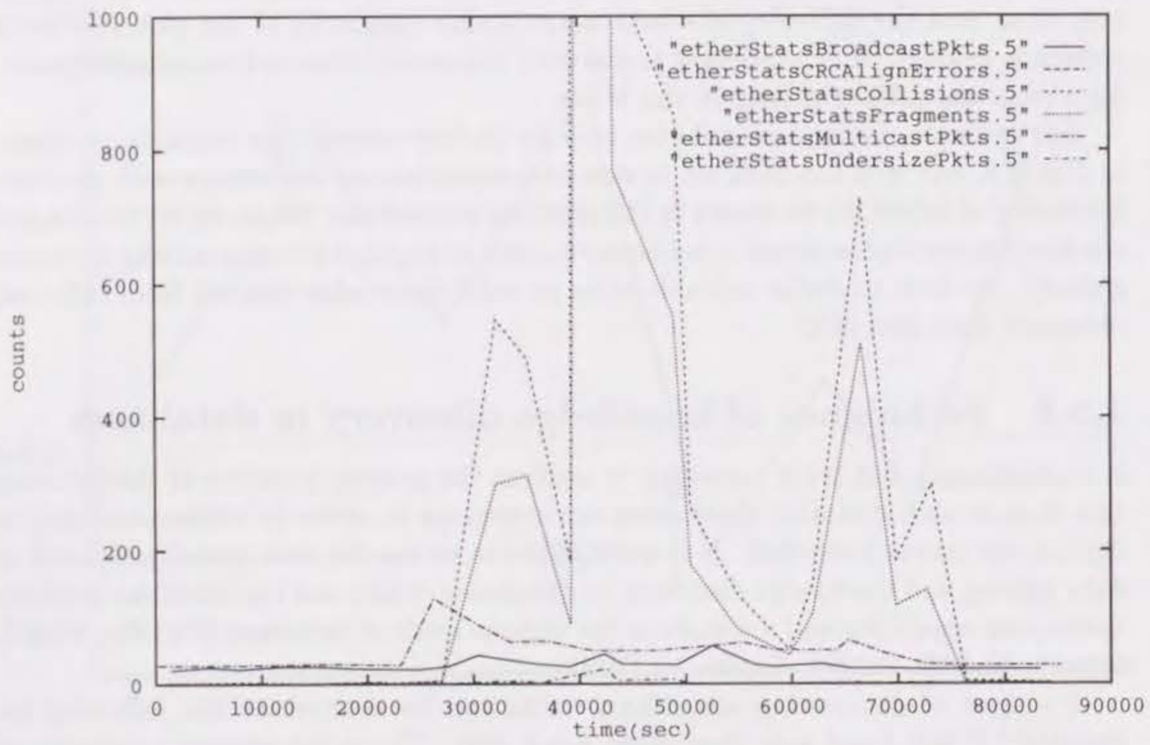

Figure 1.8: Characteristics of multiple attributes.

Moreover, the attribute oriented induction algorithm also decrease the computational complexity of a database learning process. The cluster of actual data with dynamics is collected during the observation time using data sampling technique[Kawa91], and knowledge rules regarding to the status of dynamic environment are derived effectively at real time. Discovered knowledge by this induction algorithm can be also associated with statistical information. Obviously, it is often desirable to derive rules expressed at higher abstract level than the primitive ones.

Moreover, in order to manage the communication network intelligently, it is essential to find the real time characteristics for *load balancing* or the *connecting status* between several network resources. Because of the dynamic, continuous and rapid changes of the information flow, it is difficult to catch the regularities and anomalies in a dynamic environment and react promptly for real-time applications.

The condition evaluator evaluates the current condition, compares it with that of the stored rules, discovers irregularities of the current status, if there exist, and executes actions to control the system.

1.3.4 Technique of composite events detection

If we would like to derive more concise knowledge from the several clusters of sampled values of multiple attributes in a network system, it is effective to change the sampling length depending on the sequences including specific events/data and so on. Then, it is also necessary to develop the biased sampling technique in order to observe sequences of events/data in a dynamic system.

We focus on the technique of composite events detection in active database[Geha92, Chak94], it offers the prompt, real-time, and intelligent reactions to the complicated sequences of events in Fig. 1.9. When we focus on the specific sequences or occurrences of composite events/data, it should be possible to increase the correctness of rules derived from the same number of tuples in data. It is possible to adopt the sampling technique based on the occurrences of composite events detection instead of periodical sampling method.

In order to develop biased sampling technique based on composite events/data detection, we examine the four semantics of composite events using the notion of a global event history[Chak94].

In recent, chronicle, continuous and cumulative contexts, several combinations of the initiating events and terminating events are detected.

- Recent; In this context, only the most recent occurrence of the initiator for event that has started the detection of that event is used.

- Chronicle; In this context, for an event occurrence, the initiator, terminator pair is unique, the oldest initiator is paired with the oldest terminator for each event.

- Continuous; In this context, each initiator of an event starts the detection of that event. A terminator event occurrence may detect one or more occurrences of the same event.

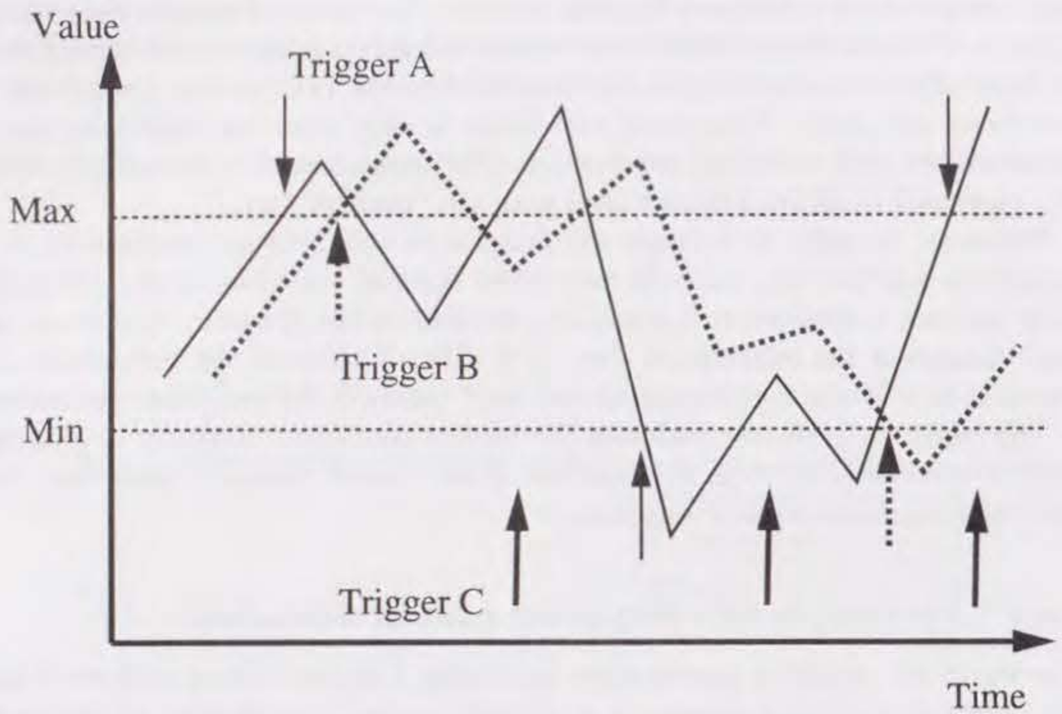

Figure 1.9: Triggering by values of multiple attributes.

- Cumulative; In this context, for each constituent event, all occurrences of the event are accumulated until the composite event is detected.

It should be noted that, it is often unrealistic to analyze a complete set of primitive data even in the limited amount of memory in a database system.

Using several contexts, intelligent management for computer communication networks is presented as an example of applications for data mining.

1.4 Overview of the Dissertation

In this thesis, we have considered the intelligent management of the stable information networks by using the feedback information and derived knowledge from various protocols of several communication layers.

In many papers, the basic problems of instability or sensitivity phenomenon in contention type protocols has been pointed out under bursty or high load in the even one local network. Therefore, in the lower layers of communication protocols, various multiple access protocols have been proposed, developed and standardized in order to achieve the stable communication channel among many networking equipments. Especially, in order to overcome this instability problem of the network, Tsybakov and Capetanakis independently proposed an excellent protocols as collision resolution algorithms. Their protocols are based on tree algorithms or tree-based collision

resolution algorithms, they effectively use the feedback information on the physical level. It is notable that tree-based collision resolution algorithms stabilize a contention-based communication system and guarantee the maximum throughput of the channel.

However, these kinds of protocols only utilize the feedback information in the lowest level communication layer, it is too difficult to perform the global stability of the interconnected network systems. Therefore, in order to transmit various kinds of messages such as data, voice, or graphic images with different requirements for stable transmission, we focus on the intelligent management for both of local and wide area networks based on the lower and higher level feedback information. Especially, in the environment of multifarious protocols, it is important to gather and analyze high level data or information in order to exchange the status of the local and wide area networks. Thus, the major objective of this dissertation is to propose and evaluate several new protocols in order to stabilize interconnected networks using several types of intelligent protocols.

In chapter 2, we extend a CSMA/CD protocol employing the blocked access tree collision resolution algorithm as its back-off algorithm, and evaluate its performance. Especially, no bistable behavior of the mean delay versus throughput performance is shown in the TREE-CSMA/CD and the FCFS discipline is realized because of the blocked access scheme.

In chapter 3, we propose the deterministic tree algorithms with reservation mechanisms (DTA-MR) using the information from the sequence of transmitting time and the delay of transmitting time. In addition to the internal priority functions of our proposed protocol, the external priority mechanism is easily realized by adjusting the starting slot of conflict sub-sessions in the DTA-MR. By such a property, our proposed scheme is effective to transmit various kinds of messages such as *data*, *voice*, or *graphic images* with different requirements for transmission.

In chapter 4, we consider the intelligent computer network management by application of the technology of knowledge discovery and active databases. A cluster of network data is collected by a data sampling technique, and stored into management information bases (MIB). By applying our proposed techniques of knowledge discovery in a dynamic environment, the general rules which describe the traffic distribution and patterns can be summarized by an attribute-oriented induction technique. Moreover, using the technology of active database, generalized conditions can be evaluated and compared with the generalized rules for the control of the dynamic environment.

In chapter 5, we use the technology of active database to control the network systems in high level protocol layer, and we propose the sampling technique based on the occurrences of composite events in the management information base. We also evaluate the memory cost performance of the sampling method based on composite events detection in several contexts. When we have typical data mining queries in a dynamic environment, our simulation study shows that we should adopt the sampling methods based on the occurrences of events/data except chronicle context.

In chapter 6, some concluding remarks and suggestions for future research are given.

The results discussed in chapter 2 is mainly taken from [Muro86b, Kawa88a], chapter 3 from [Kawa87, Kawa88b, Kawa92a], chapter 4 from [Kawa94b, Kawa96b], and chapter 5 from [Kawa95c, Kawa96c].

Chapter 2

CSMA/CD with Tree Algorithms

2.1 Introduction

For local area networks (LANs) with bus topology, the CSMA/CD protocol has been commonly used and standardized [ANSI802.3]. However, it has been pointed out in many papers that the channel stability of CSMA/CD scheme with back-off algorithms inherently suffers if the channel traffic becomes too heavy. (See, e.g., refs. [Medi83, Good88]))

A highly effective innovation in random access schemes for slotted communication channel systems was introduced independently by Capetanakis [Cape79b, Cape79a] and, Tsybakov and Mikhailov [Tsyb78] with the new concept of a collision resolution algorithm. Their proposed algorithm is often called tree type algorithm, and as the basic property the group of terminals with collided packets is divided into subgroups algorithmically, which guarantees the channel stability. Since then, many tree type algorithms have been investigated aiming at the improvement of the system performance. (see ref. [Muro86a]) Tree type algorithms employ one of two types of access protocols, i.e., blocked access protocol [Cape79b] and free access protocol [Math85]. In the blocked access protocol, new packets are transmitted in the first slot after all previous conflicts are resolved, i.e., new packets remain blocked at their respective transmitters until the current collision resolution interval terminates. On the other hand, the free access protocol permits new packets to transmit during the collision resolution interval. The procedure of blocked access protocol is easier than that of free access protocol.

Several CSMA/CD schemes with tree type collision resolution algorithms have been proposed, and at least two organizations have already implemented these types of CSMA/CD protocols. The performance of these protocols has been evaluated by some authors for the case of free access scheme [Geor86, Moll83]. However, as for the CSMA/CD scheme with blocked access protocol, its detailed access protocol and performance analysis have not yet been presented.

In this chapter, for local area networks with bus topology, we propose a random access algorithm, TREE-CSMA/CD, which employs the tree algorithm with blocked access protocol as the back-off algorithm of the CSMA/CD scheme. For the proposed algorithm, the throughput-delay performance is theoretically analyzed, and the channel stability and the robustness are discussed. Further, we show that the proposed algorithm realizes an optimal back-off algorithm [Nomu84] under an environment of distributed channel access control. Some of the results of this chapter have already been reported in [Muro86b].

2.2 TREE-CSMA/CD Algorithms

The tree collision resolution algorithms usually employ one of two types of search algorithms, i.e., the parallel search algorithm and the depth first search algorithm [Cape79a]. In the TREE-CSMA/CD protocol, the binary parallel search algorithm is used and its outline is given as follows for the slotted communication channel.

Figure 2.1 gives the procedure of collision resolution according to the binary parallel search tree algorithm when three terminals A, B and C transmit their packets in the first slot. The root node of the Fig.2.1 corresponds to the first collision slot. Then three terminals are divided into two groups according to uniform distribution random binary numbers, 0 or 1. In Fig.2.1 no terminal generates value 0, then second slot becomes the empty slot. In the third slot, all terminals transmitted their packets, which results in a collision slot again. And in the next time, A and B generate value 0 and C generates value 1. Since we are employing the parallel search tree algorithm, the fourth slot becomes a collision slot and the fifth one becomes a success slot of C. Furthermore, A and B must generate the random value for resolving collision. In Fig.2.1 terminal A generates value 0 and terminal B generates value 1, respectively. Thus the next two slots are the success slots of A and B. In this case, the length of the collision resolution interval is 7 slots, which was shown in Fig.2.2.

If the binary depth first search algorithm is applied to the above example, terminal C refrains from its packet transmission (in the fifth slot) and waits for the collision resolution of packets transmitted from terminal A and B. This binary depth first search algorithm also requires 7 slots for collision resolution in Fig.2.3 and Fig.2.4.

Now, we can easily show the following important property of binary parallel search algorithm, which gives us the reason to use this algorithm instead of the binary depth first tree algorithm.

Property: In the collision resolution process of the binary parallel search algorithm, no more than two slots become consecutive empty slots. □

An example that two empty slots come in succession in the binary parallel search algorithm is illustrated in Fig.2.1.

For applying the above mentioned collision resolution algorithm to the back off algorithm of CSMA/CD protocol, we have to take care of the following two remarkable properties of the access mechanism of CSMA/CD.

- **Asynchronous Access Mechanism**

  The CSMA/CD protocol operates in the non-slotted (asynchronous) communication channel, though the above mentioned algorithm assumes the slotted communication channel. This mismatch can be resolved as follows.

  In the CSMA/CD scheme,since all terminals with transmitting packets (such terminals are called active terminals) sense the channel, they can recognize the end of carrier of packets successfully transmitted as well as the end of carrier of jam signals which are transmitted for letting all active terminals know that collisions are occurred in the channel. For realizing asynchronous

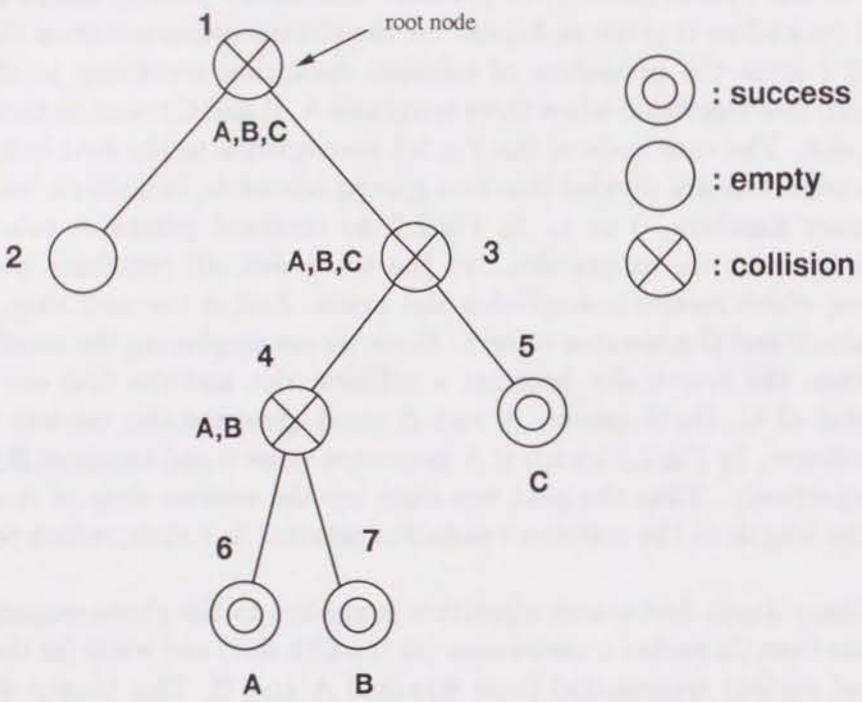

Figure 2.1: Example of a tree graph for parallel search.

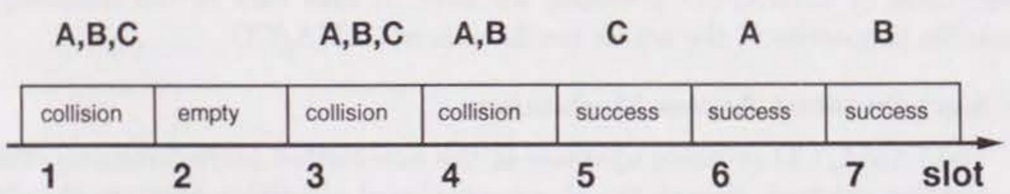

Figure 2.2: Example of collision resolution for Fig.2.1.

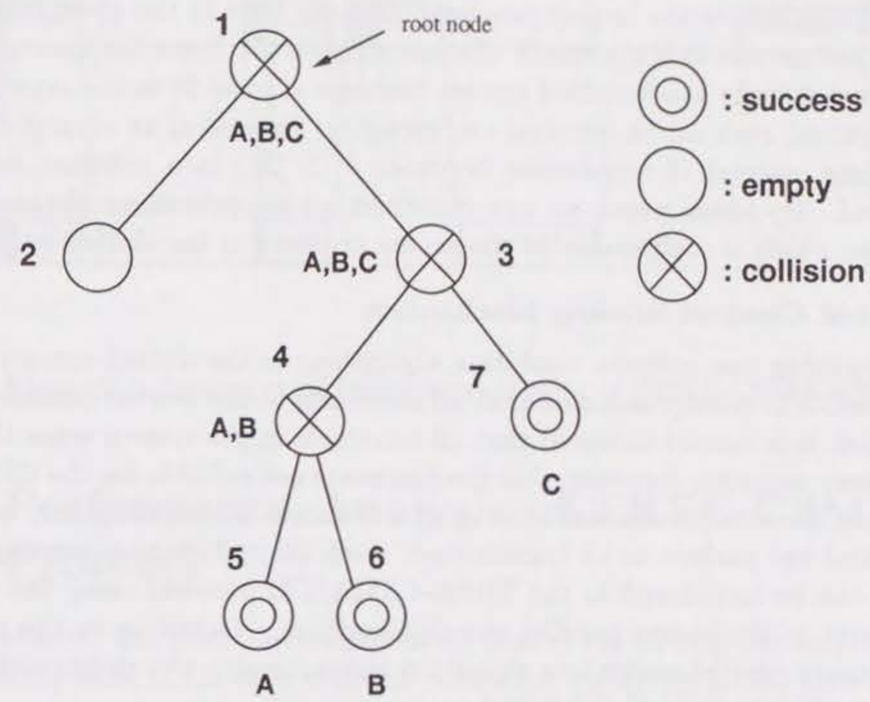

Figure 2.3: Example of a tree graph for binary depth first search.

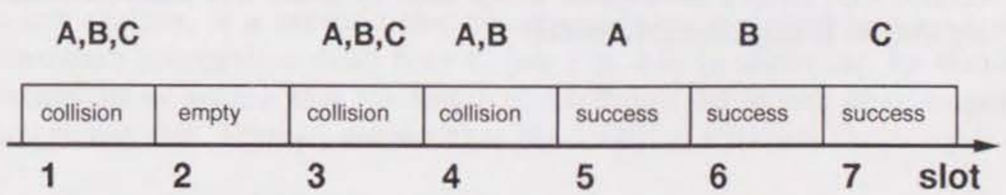

Figure 2.4: Example of collision resolution for Fig.2.3.

access mechanism in the TREE-CSMA/CD scheme, the end of a success slot (the end of a collision slot) corresponds to the end of a packet successfully transmitted (the end of a jam signal), respectively, and by these ends of carriers the channel time is synchronized.

Now let us denote the largest propagation delay time in the given bus system by τ, and assume that the length of a jam signal is 2τ. Since the time span of an empty slot of the above slotted system becomes at most 2τ in the asynchronous bus system, each active terminal can recognize the end of an empty slot when the time interval of non-carrier becomes I ($> 2\tau$) in a collision resolution interval. By these ways, we can construct an asynchronous channel access scheme which is comparable to the access protocol in the slotted system.

- **Limited Channel Sensing Mechanism**

For realizing tree collision resolution algorithms in the slotted communication channel, it is usually assumed that all terminals in the slotted communication channel, it is usually assumed that all terminals in the system sense the channel every moment. However, this mechanism is not suitable for the CSMA/CD scheme, because its channel sensing of a terminal is operating only when the terminal has packets to be transmitted. Such limited channel sensing mechanism can be introduced to the TREE-CSMA/CD protocol using the previous property of the binary parallel search algorithm. According to the property, the binary parallel search tree algorithm has successive two empty slot at most in one collision resolution interval.

Therefore, each active terminal can recognize the end of collision resolution interval when empty slots are continued for three slots. In the TREE-CSMA/CD, each active terminal considers that a new collision resolution interval starts if the time interval of non-carrier becomes W ($> 2I + 2\tau$). In such a way, each active terminal is not required to sense the carrier after it becomes inactive. We will show a snapshot of the TREE-CSMA/CD channel in Figure 2.5, which corresponds to that of the slotted tree algorithm in Figure 2.2. In Figure 2.5, terminal A and terminal C are located at the different ends of communication channel, and terminal B is located at its center. As the mechanism for each terminal to recognize the slot for transmitting its packet in the TREE-CSMA/CD, a stack mechanism which used by usual tree collision resolution algorithms is employed.[Muro86b].

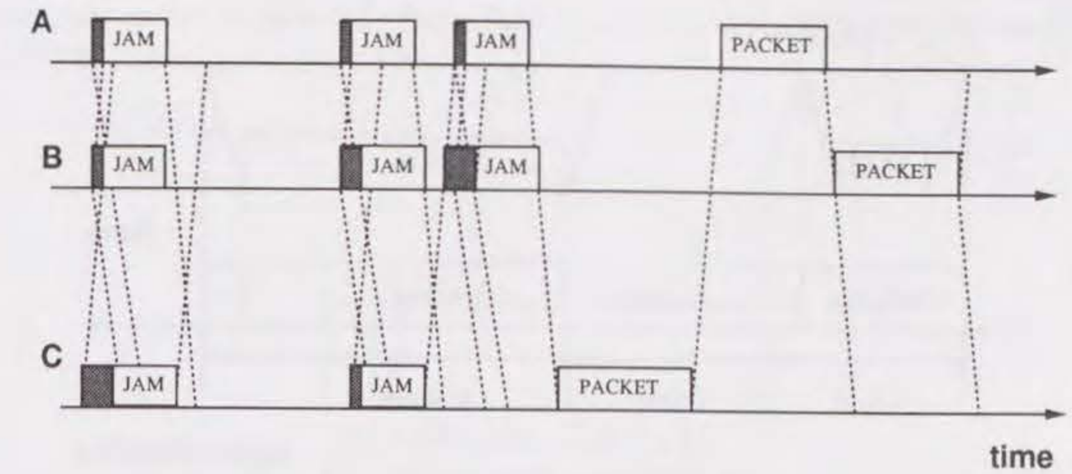

Figure 2.5: Snapshot of collision resolution of TREE-CSMA/CD.

2.3 Performance Analysis of TREE-CSMA/CD Protocol

Massey [Mass80] has proposed a analysis method of the throughput and mean transmission delay time of the tree collision resolution algorithm in the slotted communication system, where the channel time is slotted by the time interval to transmit a packet. In this section, this analysis method will be extended to approximately analyze the performance of TREE-CSMA/CD protocol.

2.3.1 First and second moment of collision resolution time

For a collision with the multiplicity (i.e., the number of packets collided in a slot) of k, its collision resolution time (slots) has the following relations:

$$V(k) = S(k) - [M(k)]^2, \tag{2.1}$$

where $M(k)$ is the first moment of the length of the collision resolution interval, and $S(k)$ ($V(k)$) means its second moment (variation), respectively.

In our analysis, it is assumed that the channel time is slotted by a multiple of the maximum propagation delay time τ. (see Fig. 2.6) In particular, for simplicity of analysis, let us assume that the length of a collision slot as well as an empty slot is equal to one slot. Further, assume that the length of a success slot is equal to L slots.

First, let us obtain the first moment $M(k)$. If k is equal to 0 or 1, then the channel state corresponds to an empty slot or an success slot, respectively. Therefore, $M(k)$ obviously satisfies the following equations:

$$M(0) = 1, \qquad M(1) = L\ . \tag{2.2}$$

If the multiplicity of k is larger than 1, the collision occurs in the slot, and in our TREE-CSMA/CD scheme this collision will be resolved by generating uniformly

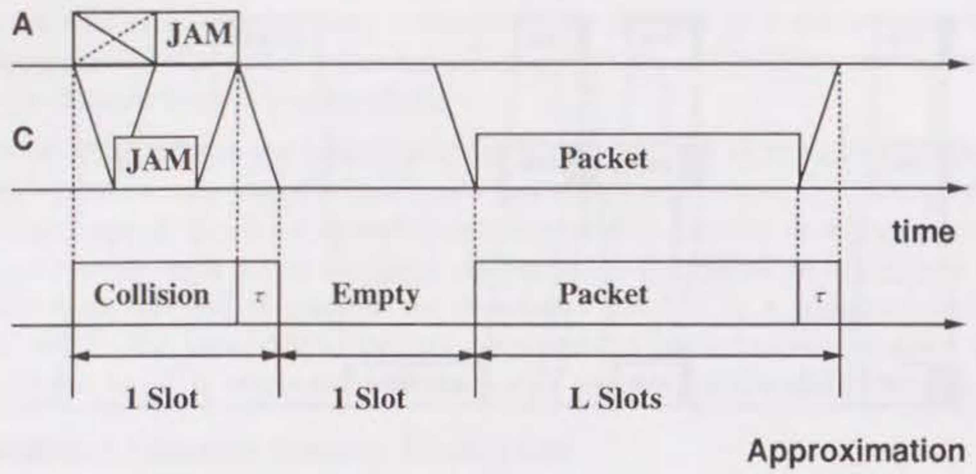

Figure 2.6: Slotted approximation of resolution periods for TREE-CSMA/CD protocol.

distributing binary random numbers (i.e., flipping an unbiased "two-sided coin" with values 0,1). Now assume that i terminals out of k terminals involved in the collision generated value 0 (i.e., $(k-i)$terminals generated value 1) and k terminals are divided into two groups. Let $P(k,i)$ denote the probability that such event occurs. Then $P(k,i)$ is given by

$$P(k,i) = \binom{k}{i} 2^{-k} \tag{2.3}$$

and this $P(k,i)$ obviously satisfies the relation $P(k,k-i) = P(k,i)$. Considering that the collision with multiplicity k will be resolved by resolving two collisions with multiplicity i and $(k-i)$, $M(k)$ satisfies the following equation under the condition that the above event is occurred.

$$M(k) = 1 + M(i) + M(k-i), \tag{2.4}$$

where 1 corresponds to the initial collision with multiplicity k using eq.(2.3) and eq.(2.4), we obtain the following equation of $M(k)$.

$$\begin{aligned} M(k) &= 1 + \sum_{i=0}^{k} [M(i) + M(k-i)] \cdot P(k,i) \\ &= 1 + 2\sum_{i=0}^{k} M(i)P(k,i) \end{aligned} \tag{2.5}$$

Further, from eq.(2.5), $M(k)$ is provided by the following recursive equation:

$$M(k) = \left[1 + 2\sum_{i=0}^{k-1} M(i)P(k,i)\right] / (1 - 2^{-k+1}). \tag{2.6}$$

Using eq.(2.2), we calculated $M(k)$ for $k = 0, 1, \cdots, 6$ and illustrated the obtained numerical results in Table 2.1. From Table 2.1, we can approximately evaluate $M(k)$ as follows:

$$M(k) \approx (1.9 + L)k - 1.$$

k	$M(k)$
0	1
1	L
2	$3 + 2L$
3	$14/3 + 3L = 4.667 + 3L$
4	$137/21 + 4L = 6.524 + 4L$
5	$8.419 + 5L$
6	$10.31. + 6L$

Table 2.1: Mean resolution time for multiplicity k.

Here, introducing coefficients $\alpha_\ell(m)$ and $\alpha_u(m)$, let us present in the following inequality upper and lower bounds of $M(k)$ which are effective in case that $k \geq m$.

$$\alpha_\ell(m)k - 1 \leq M(k) \leq \alpha_u(m)k - 1 \qquad (k \geq m) \tag{2.7}$$

The derivation process of $\alpha_\ell(m)$ and $\alpha_u(m)$ are shown in Appendix A and values of $\alpha_\ell(m)$ and $\alpha_u(m)$ are given in Table 2.2 for $m = 2, 3, 4, 5$. Referring to the obtained results in Table 2.1, we can verify that the following lower and upper bounds are provided for $M(k)$.

m	$\alpha_u(m)$	k	$\alpha_\ell(m)$	k
2	$2 + L$	2	$1 + L$	∞
3	$2 + L$	∞	$1.8750 + L$	4
4	$1.8965 + L$	14	$1.8810 + L$	4
5	$1.8867 + L$	8	$1.8810 + L$	∞

Table 2.2: Upper and lower bounds for the first moment $M(k)$.

$$(1.8810 + L)k - 1 \leq M(k) \leq (1.8867 + L)k - 1 \qquad (k \geq 4) \tag{2.8}$$

Next, let us consider the conditional second moment $S(k)$ as well as the conditional variance $V(k)$ of the collision resolution interval (denoted by Y) for the collision with multiplicity $X(= k)$. Let X_0 denote the number of terminals generating value

0 for resolving the collision with multiplicity $X(=k)$, and $E(A)$ represent the mean value of A. Then, $S(k)$ is given by the following equation:

$$\begin{aligned}
S(k) &= \sum_{i=0}^{k} E(Y^2|X=k, X_0=i)P(k,i) \\
&= \sum_{i=0}^{k}[V(Y|X=k,X_0=i)+E^2(Y|X=k,X_0=i)]P(k,i) \\
&= \sum_{i=0}^{k}[V(i)+V(k-i)+\{1+M(i)+M(k-i)\}^2]P(k,i) \\
&= \sum_{i=0}^{k}[2V(i)+\{1+M(i)+M(k-i)\}^2]P(k,i) \qquad (k \geq 2) \qquad (2.9)
\end{aligned}$$

Applying eq.(2.1) to eq.(2.9), $V(k)$ is provided by the following recursive equation:

$$V(k) = \frac{\left[2\sum_{i=0}^{k-1} V(i)P(k,i) + \sum_{i=0}^{k}\{1+M(i)+M(k-i)\}^2 P(k,i) - \{M(k)\}^2\right]}{(1-2^{-k+1})}, \qquad (2.10)$$

where in the case that k is equal to 0 or 1, the following equations are obviously satisfied.

$$V(0)=0, \quad V(1)=0 \qquad (2.11)$$

Using eq.(2.9), eq(2.10) and eq.(2.11), we calculated values of $V(k)$ and $S(k)$ for $k=0,1,\cdots,6$, and gave them in Table 2.3.

Furthermore, applying Jensen's inequality [Vite79] to a part of eq.(2.10), we can obtain the following inequality:

$$\begin{aligned}
&\sum_{i=0}^{k}(1+M(i)+M(k-i))^2P(k,i) \\
\geq &\left[\sum_{i=0}^{k}(1+M(i)+M(k-i))P(k,i)\right]^2 = (\{M(k)\}^2). \qquad (2.12)
\end{aligned}$$

Substituting eq.(2.12) into eq.(2.10), we can give a lower bound of $V(k)$ as follows:

$$V(k) \geq 2\sum_{i=0}^{k-1} V(i)P(k,i)/(1-2^{-k+1}).$$

By the same manner as that of the evaluation of $M(k)$, we can get the following equation $\beta_\ell(m)$ which gives the lower bound of $V(k)$, i.e., $V(k) \geq \beta_\ell(m) \quad (k \geq m)$.

$$\beta_\ell(m) = \inf_{k \leq m}\left[\sum_{i=0}^{m-1}\binom{k}{i}V(i)/\sum_{i=0}^{m-1}\binom{k}{i}i\right] \qquad (2.13)$$

Similarly, the upper bound of $V(k)$, i.e., $V(k) \leq \beta_u(m) \quad (k \geq m)$, can be obtained and is given by

$$\beta_u(m) = \sup_{k \geq m}\left[\left\{\sum_{i=0}^{m-1}\binom{k}{i}V(i)+\alpha_u(m)k-\frac{1}{2}\right\}/\sum_{i=0}^{m-1}\binom{k}{i}i\right]. \qquad (2.14)$$

k	$V(k)$
0	0
1	0
2	8
3	88/9=9.78
4	13.53
5	16.94
6	20.32

k	$S(k)$
0	1
1	L^2
2	$8+(3+2L)^2$
3	$8/9+(14/3+3L)^2$
4	$13.53+(137/21+4L)^2$
5	$16.94+(8.419+5L)^2$
6	$20.32+(10.31.+6L)^2$

Table 2.3: Variance $V(k)$ and second moment $S(k)$.

In Table 2.4, we provide values of $\beta_\ell(m)$ and $\beta_u(m)$ for $m=3,4,\cdots,7$. According to the obtained results, we can provide the following lower and upper bounds for the value $V(k)$.

m	$\beta_u(m)$	k	$\beta_\ell(m)$	k
3	4	∞	2.666	3
4	$3.363+L/7$	4	3.111	4
5	$3.391+L/15$	5	3.272	5
6	$3.391+L/31$	6	3.333	6
7	$3.3884+L/63$	7	3.359	7

Table 2.4: Upper and lower bounds for β.

$$3.359k \leq V(k) \leq \left(3.388+\frac{L}{63}\right)k \qquad (k \geq 4) \qquad (2.15)$$

In the above performance evaluation of TREE-CSMA/CD, we only considered a single collision resolution interval independent from other collision resolution intervals. Here let us look into a chain of successive collision resolution intervals in the TREE-CSMA/CD protocol. For realizing the limited channel sensing mechanism, between two successive collision resolution interval, there exists a time interval with length N as described in section 2.2. Thus, $M(k)$ obtained above must be increased by 3(slots), and then $S(k)$ must be also updated according to the change of $M(k)$, though we need not update $V(k)$. From eq.(2.1), eq.(2.8), and eq.(2.15), the first moment and the second moment of the collision resolution time of the TREE-CSMA/CD protocol are evaluated as follows:

$$(1.8810+L)k+2 \le M(k) \le (1.8867+L)k+2 \qquad (k \ge 4) \tag{2.16}$$

$$S(k) \le \{(1.8867+L)k+2\}^2 + \left(3.388+\frac{L}{63}\right)k \qquad (k \ge 3) \tag{2.17}$$

$$S(k) \ge \{(1.8810+L)k+2\}^2 + 3.359k \qquad (k \ge 3) \tag{2.18}$$

2.3.2 Throughput vs. mean transmission delay time

Assume that a new packet arrives according to the independent Poisson process. Let λ (packets/slot) denote the total average packet arrival rate in a slot. Furthermore, assume that the system consists of infinite number of terminals and all newly arriving packets are transmitted according to the TREE-CSMA/CD protocol. Here, let Y_i denote the length of the i-th collision resolution interval, and X_i denote the number of the packets transmitted in the first slot of the i-th collision resolution interval. Please refer to Fig. 2.7 for the notation of Y_i and X_i. As the initial conditions, we give $X_0 = 0$ and $Y_0 = 1$.

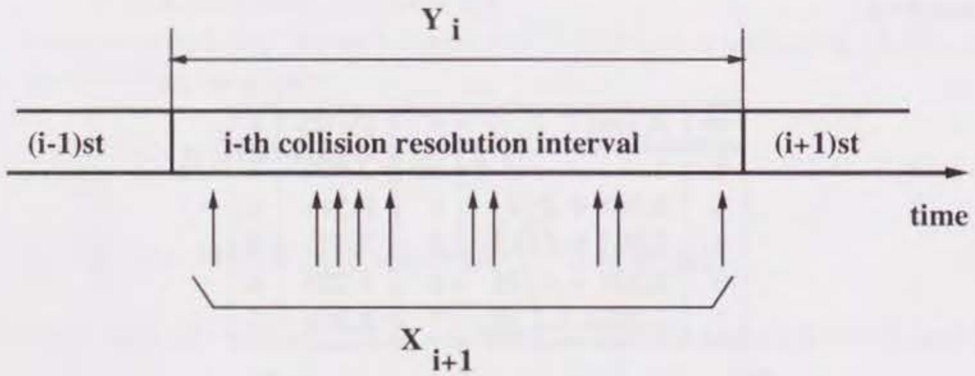

Figure 2.7: Relation of X_i and Y_i.

According to the assumption of packet arrival, we can obtain the following equation:

$$P(X_{i+1}=k|Y_i=M) = \frac{(\lambda M)^k}{k!}\exp(-\lambda M) \qquad (k=0,1,2,3,\cdots). \tag{2.19}$$

Considering the conditional mean value of X_{i+1} in eq.(2.19), we get the following equation:

$$E(X_{i+1}|Y_i=M) = \lambda M. \tag{2.20}$$

Moreover, multiplying both sides of eq.(2.20) by $P(Y_i = M)$ and summing over all M, we can obtain the following equation:

$$E(X_{i+1}) = \lambda E(Y_i). \tag{2.21}$$

Here, note that the equation $E(Y_i|X_i = k) = M(k)$ holds. Using this equation and the inequality giving the upper bound of $M(k)$ in eq.(2.16), we can show the following inequality:

$$E(Y_i|X_i=k) \le (2+L)k+2-\delta_{0k}-\delta_{1k} \qquad (k \ge 0), \tag{2.22}$$

where δ_{ij} (Kronecker's delta) is defined by $\delta_{ij} = 1$ $(i = j)$, $\delta_{ij} = 0$ $(i \ne j)$. Multiplying eq.(2.22) by $P(X_i = k)$ and summing over k, we obtain

$$E(Y_i) \le (2+L)E(X_i)+2-P(X_i=0)-P(X_i=1).$$

Now, using eq.(2.21) and the lower bound value 1 of $P(X_i = 0)$ and $P(X_i = 1)$, we can show the inequality given by

$$E(X_{i+1}) - (2+L)\lambda E(X_i) \le 2.$$

Unfolding the above recursive inequality and substituting the initial condition to the obtained inequality, we can get the following inequality:

$$E(X_i) \le \frac{2}{1-(2+L)\lambda}[1-\{(2+L)\lambda\}^i] \qquad (i \ge 0). \tag{2.23}$$

Eq.(2.23) shows that if $\lambda < 1/(2+L)$, $E(X_i)$ has a finite limit value as $i \to \infty$. On the other hand, using the inequality giving the lower bound of $M(k)$ in eq.(2.16), we can give the following inequality:

$$E(X_i) \ge \frac{1}{1-(1+L)\lambda}[1-\{(1+L)\lambda\}^i] \qquad (i \ge 0). \tag{2.24}$$

Eq.(2.24) shows that if $\lambda > 1/(1+L)$, $E(X_i)$ does not have any finite value as $i \to \infty$.

Here, let $E(X_\infty)$ denote the value defined by $\lim_{i\to\infty} E(X_i)$. Replacing the bounding values employed above by tighter ones shown in eq.(2.16), we can obtain the following results:

$E(X_\infty)$ is finite if

$$\lambda < \frac{1}{1.8867+L}(packets/slot),$$

and

$E(X_\infty)$ is infinite if

$$\lambda > \frac{1}{1.8810+L}(packets/slot).$$

By the above discussion, it becomes clear that the stability condition of TREE-CSMA/CD is given by $\lambda < 1/(1.8867 + L)$, and an upper bound of the system is given by $L/(1.8867 + L)$. In our analysis, L compares to the packet length and its value is equal to tens under the ANSI/IEEE standard [ANSI802.3]. Therefore, the difference between two crucial values (i.e., one gives an upper bound for the channel stability and the other does a lower bound for the channel instability) becomes very small. This gives a proof that our analysis is sufficiently sound technically.

Under the condition that the system has the steady state, i.e., $\lambda < 1/(1.8867+L)$, we define π_k and $P(Y_\infty = M)$ by $\pi_k = P(X_\infty = k) \stackrel{\text{def}}{=} \lim_{i\to\infty} P(X_i = k)$ $(k = 0, 1, 2, \cdots)$ and $P(Y_\infty = M) \stackrel{\text{def}}{=} \lim_{i\to\infty} P(Y_i = M)$.

Now, among the first n collision resolution intervals, let n_k (n'_M) denote the number of collision resolution intervals for the collision with multiplicity k (the number of collision resolution intervals with length M), respectively. Then, above π_k and $P(X_\infty = M)$ are given as follows:

$$\begin{aligned}\pi_k &= \lim_{n\to\infty} \frac{n_k}{n} \qquad (k = 0, 1, 2, \cdots) \\ P(Y_\infty = M) &= \lim_{n\to\infty} \frac{n'_M}{n}. \end{aligned} \tag{2.25}$$

Here, let variable Y_a denote the length of collision resolution interval in progress when a packet arrives at a terminal. Then, $P(Y_a = M)$ satisfies the following equation:

$$P(Y_a = M) = \lim_{n\to\infty} \frac{Mn'_M}{\sum_{i=1}^{\infty} in'_i} = \lim_{n\to\infty} \frac{Mn'_M/n}{(\sum_{i=1}^{\infty} in'_i)/n} = \frac{MP(Y_\infty = M)}{E(Y_\infty)}.$$

Moreover, multiplying both sides of the above equation by M and summing over M, we obtain

$$E(Y_a) = \frac{E(Y_\infty^2)}{E(Y_\infty)},$$

where $E(Y_\infty^2) \stackrel{\text{def}}{=} \lim_{i\to\infty} E(Y_i^2)$. Next let variable Y_d denote the length of collision resolution interval in which the same randomly chosen packet departs from the system, and let variable X_d denote the total number of packets transmitted in this collision resolution interval. Multiplying both sides of $E(X_d|Y_a = M) = \lambda M$ by $P(Y_a = M)$ and summing over M, the following equation will be given.

$$E(X_d) = \lambda E(Y_a) \tag{2.26}$$

Furthermore, using eq.(2.16), eq.(2.17) and eq.(2.18), we can obtain the following four inequalities:

$$E(Y_d|X_d = k) = M(k) \le (1.89 + L)k + 2 - \delta_{0k} - 0.89\delta_{1k} + 0.22\delta_{2k}, \tag{2.27}$$

$$E(Y_d|X_d = k) = M(k) \ge (1.88 + L)k + 2 - \delta_{0k} - 0.88\delta_{1k} + 0.24\delta_{2k}, \tag{2.28}$$

$$\begin{aligned} S(k) \le\ & (1.89 + L)^2k^2 + (10.948 + \frac{253}{63}L)k + 4 - 3\delta_{0k} \\ & -(1.796L + 9.52)\delta_{1k} + (0.8483L + 3.82)\delta_{2k}, \end{aligned} \tag{2.29}$$

$$\begin{aligned} S(k) \ge\ & (1.88 + L)^2k^2 + (10.883 + 4L)k + 4 - 3\delta_{0k} \\ & -(1.76L + 9.42)\delta_{1k} + (0.96L + 4.1)\delta_{2k}. \end{aligned} \tag{2.30}$$

For simplicity of description, let us rewrite the above inequalities as follows:

$$E(Y_d|X_d = k) = M(k) \le Ak + B - \delta_{0k} - C\delta_{1k} + D\delta_{2k}, \tag{2.31}$$

$$E(Y_d|X_d = k) = M(k) \ge Ek + F - \delta_{0k} - G\delta_{1k} + H\delta_{2k}, \tag{2.32}$$

$$S(k) \le Pk^2 + Qk + R - 3\delta_{0k} - S\delta_{1k} + T\delta_{2k}, \tag{2.33}$$

$$S(k) \ge Uk^2 + Vk + W - 3\delta_{0k} - X\delta_{1k} + Y\delta_{2k}. \tag{2.34}$$

According to the derivation process shown in Appendix B, $E(Y_d)$ can be evaluated as follows:

$$\begin{aligned} E(Y_d) \le\ & A\lambda E(Y_a) + B + D \\ & -(C\lambda + D + D\lambda + 1)\exp(-\lambda E(Y_a)), \end{aligned} \tag{2.35}$$

$$\begin{aligned} E(Y_d) \ge\ & E\lambda E(Y_a) + F - G - (1 - G)\exp(-\lambda) \\ & + \left(\frac{\lambda^2}{2}G + \frac{\lambda^2}{2}H\right)\exp(-\lambda E(Y_a)). \end{aligned} \tag{2.36}$$

Moreover, according to the derivation process shown in Appendix B, $E(Y_a)$ can be evaluated as follows:.

$$E(Y_a) \ge \frac{(U + V)\lambda - X\dfrac{1}{L+3}}{1 - U\lambda^2}, \tag{2.37}$$

$$E(Y_a) \le \frac{(P + Q)\lambda + R}{1 - P\lambda^2}. \tag{2.38}$$

Let us denote the right hand side of eq.(2.35), eq.(2.36), eq.(2.37), and eq.(2.38) by $UE(Y_d)$, $LE(Y_d)$, $LE(Y_a)$, and $UE(Y_a)$, respectively.

Now the following three properties are important for obtaining the throughput versus packet transmission delay time characteristics of the TREE-CSMA/CD protocol.

1. On the average, the randomly-chosen packet is considered to arrive at a terminal at the midpoint of a collision resolution interval in progress.

2. At the latest, a newly arriving packet is transmitted successfully in the last slot of the next collision resolution interval.

3. On the average, a newly arriving packet is transmitted successfully at the midpoint of the next collision resolution interval.

For evaluating the upper bound (lower bound) of mean transmission delay time versus throughput, we shall respectively employ value of 5τ (3τ) for one slot time in Fig. 2.6.

Furthermore, depending on which property of (2) or (3) is applied to the evaluation, we will have the following four upper or lower bound values.

Upper Bound (1 slot is approximately estimated as 5τ.):

$$\left(\frac{1}{2}UE(Y_a) + UE(Y_d)\right)/L + 1 \tag{2.39}$$

$$\left(\frac{1}{2}UE(Y_a) + \frac{1}{2}UE(Y_d)\right)/L + 1 \tag{2.40}$$

Lower Bound (1 slot is approximately estimated as 3τ.):

$$\left(\frac{1}{2}LE(Y_a) + LE(Y_d)\right)/L + 1 \tag{2.41}$$

$$\left(\frac{1}{2}LE(Y_a) + \frac{1}{2}LE(Y_d)\right)/L + 1 \tag{2.42}$$

As the results, we can obtain the upper bound as well as the lower bound of mean transmission delay time normalized by one packet transmission time.

2.4 Performance of TREE-CSMA/CD

In this section, by means of simulation studies, the performance of the TREE-CSMA/CD protocol will be evaluated under the comparison with that of CSMA/CD which employs conventional back-off algorithms.

2.4.1 Simulation models

Let us assume the following simulation model.

1. There exists 100 terminals in the local area network system with bus topology, and these terminals are uniformly distributed along the bus. The propagation delay time between any two terminals is taken into account.

2. When a terminal detects the collision in the channel, it transmits the jam signal for a constant time. The propagation delay time of jam signal is also taken into account.

3. The source model that will be used here is the Poisson source model, which assumes the existence of a finite number of independent identical sources. Moreover, reflecting the actual system environment, assume that each terminal has a buffer with the capacity of 6 packets.

4. In the TREE-CSMA/CD protocol, I (time interval of idle state) is equal to 3τ, and N (time interval between two successive collision resolution intervals) is equal to 9τ.

5. As the conventional back-off algorithms, we consider the LIB (linear incremental back-off), the BEB (Binary exponential back-off), and the FMB (fixed mean back-off) (see, e.g., [Nomu84]). Also we employ the 1-persistent model as the channel access mechanism.

6. The other fundamental parameters are given in Table 2.5. These parameter values are due to the ANSI/IEEE standard of CSMA/CD protocol for the bus type LAN[ANSI802.3]. To validate that the TREE-CSMA/CD has favorable performance characteristics, though it operates under the distributed control, we introduce another CSMA/CD scheme, i.e., CSMA/CD protocol with an optimal back-off algorithm. In usual distributed systems, it is hard for each terminal to estimate the number of active terminals (let A denote this number). However, if each terminal can recognize this value A just before its packet retransmission, the protocol in which each ready terminal transmits its packet with probability $1/A$ becomes one of optimal back-off algorithms. This protocol is called OPA [Nomu84], and it is also involved in our simulation studies.

Basic parameters	value
Number of terminals	100 stations
Maximum propagation delay time	5 μ sec
Capacity	10 Mbps
Length of packet	5000bits
Length of JAM signal	100bits

Table 2.5: Basic parameters for numerical analysis.

2.4.2 Performance evaluation

Fig. 2.8 and Fig. 2.9 show the performance of throughput versus mean transmission delay time and that of throughput versus coefficient of variation of transmission delay time of each packet, respectively. In these figures, only mean values are illustrated since the confidence interval of 95(%) of numerical results is too narrow in each case. From these two figures we can see several interesting points. Concerning the mean transmission delay time, the TREE-CSMA/CD protocol has almost similar performance to that of the CSMA/CD with conventional back-off algorithms. On the other hand, as for the coefficient of variation of transmission delay time, the TREE-CSMA/CD has much smaller value than that of the other CSMA/CD with conventional back-off algorithms. This supports the fact that in the TREE-CSMA/CD protocol the packet transmission is serviced according to the First-Come First-Served (FCFS) discipline and the packet transmission delay time becomes almost a constant value. Next, comparing the performance of the TREE-CSMA/CD with that of the OPA for the above two performance measures, these two protocols have almost the same performance. This shows that the TREE-CSMA/CD protocol realizes a very good back-off algorithm instead of the distributed control.

In the above performance evaluation study, we did not compare our blocked access TREE-CSMA/CD protocol with that of the CSMA/CD protocol with free access scheme. This is due to the consideration that these two protocols have not a significant difference in practical application. The most effective factor that makes these two protocols different in the mean delay versus throughput performance is the redundant time interval N which is required to realize the limited channel sensing mechanism in the blocked access TREE-CSMA/CD. However, this time interval N is too small as compared with the packet transmission time and is required only once for a collision resolution interval. Especially in the heavy traffic environment, a collision resolution interval becomes very long, and therefore the time interval N is relatively very small and is possible to be neglected. Furthermore, due to the property of tree collision resolution algorithm, the collision resolution time is not so different between the above two access schemes, it is conclusive that these two protocols have almost similar mean transmission delay versus throughput performance.

By such observation as well as the good properties of the blocked access TREE-CSMA/CD which will be discussed in sections 2.6 and 2.7, we have focused on the performance of the blocked access TREE-CSMA/CD protocol.

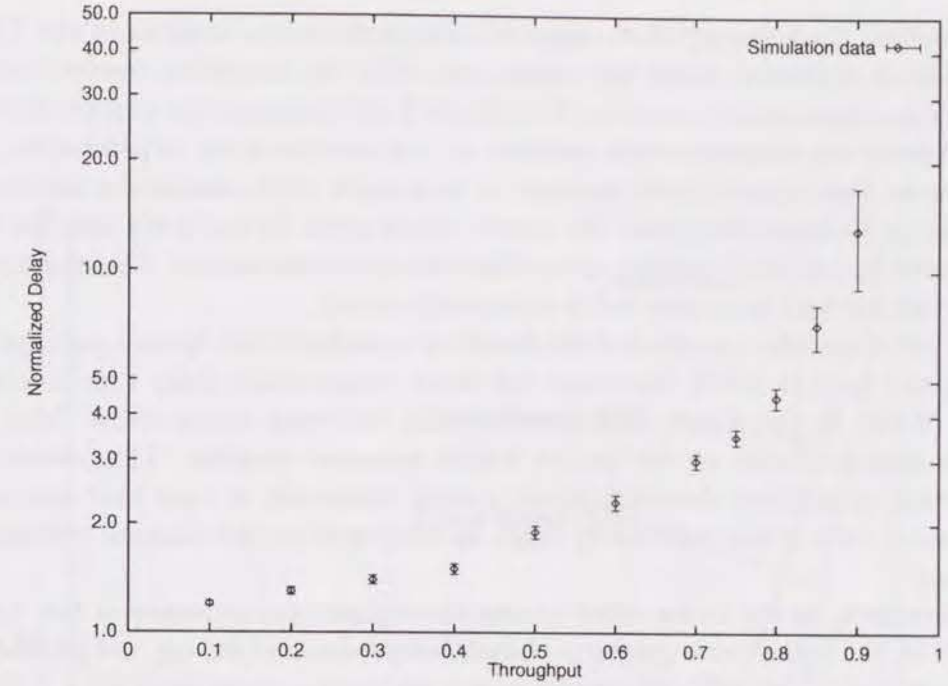

Figure 2.8: Mean delay versus throughput.

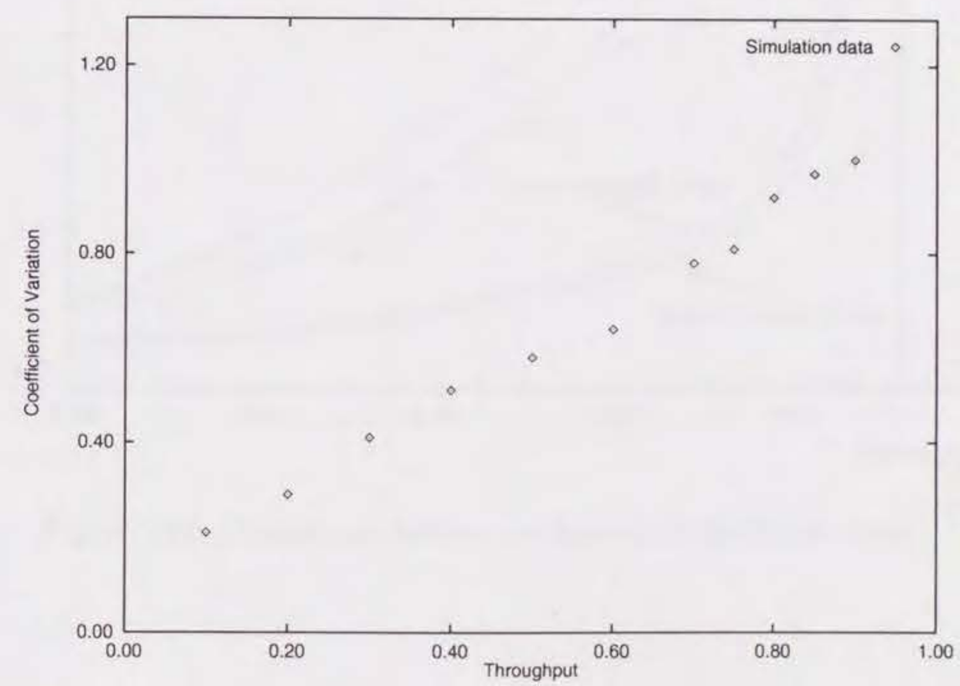

Figure 2.9: Coefficient of variation versus throughput.

2.5 Numerical Results

In this section, the accuracy of our approximate performance analysis of the TREE-CSMA/CD is examined under the comparison with the numerical results obtained by simulation experiments in section 2.4. Figure 2.10 illustrates the numerical results obtained from our approximation analysis as well as simulation experiments. This figure shows that approximate analysis is well agree with simulation results. In particular, it becomes clear that the upper bound given by eq.(2.40) and the lower bound given by eq.(2.41) provide very effective evaluation values. This means that our analysis method in section 2.4 is technically sound.

Now let us consider the effect of the length of a packet to the system performance, referring to Fig. 2.11 which illustrates the mean transmission delay time calculated from eq.(2.40). In this figure, it is observed that the mean transmission delay time increases monotonically as the packet length becomes smaller. This means that the function of collision detection doesn't work effectively in case that the packet transmission time is not sufficiently large as compared to the channel propagation delay time.

Furthermore, in the mean delay versus throughput performance of the TREE-CSMA/CD, the undesirable property of *bistability behavior* (see e.g., ref.[Muro86a]), which leads to the instability of random access protocols such as the CSMA/CD with conventional back-off algorithms is not conspicuous. This guarantees the channel stability of the TREE-CSMA/CD.

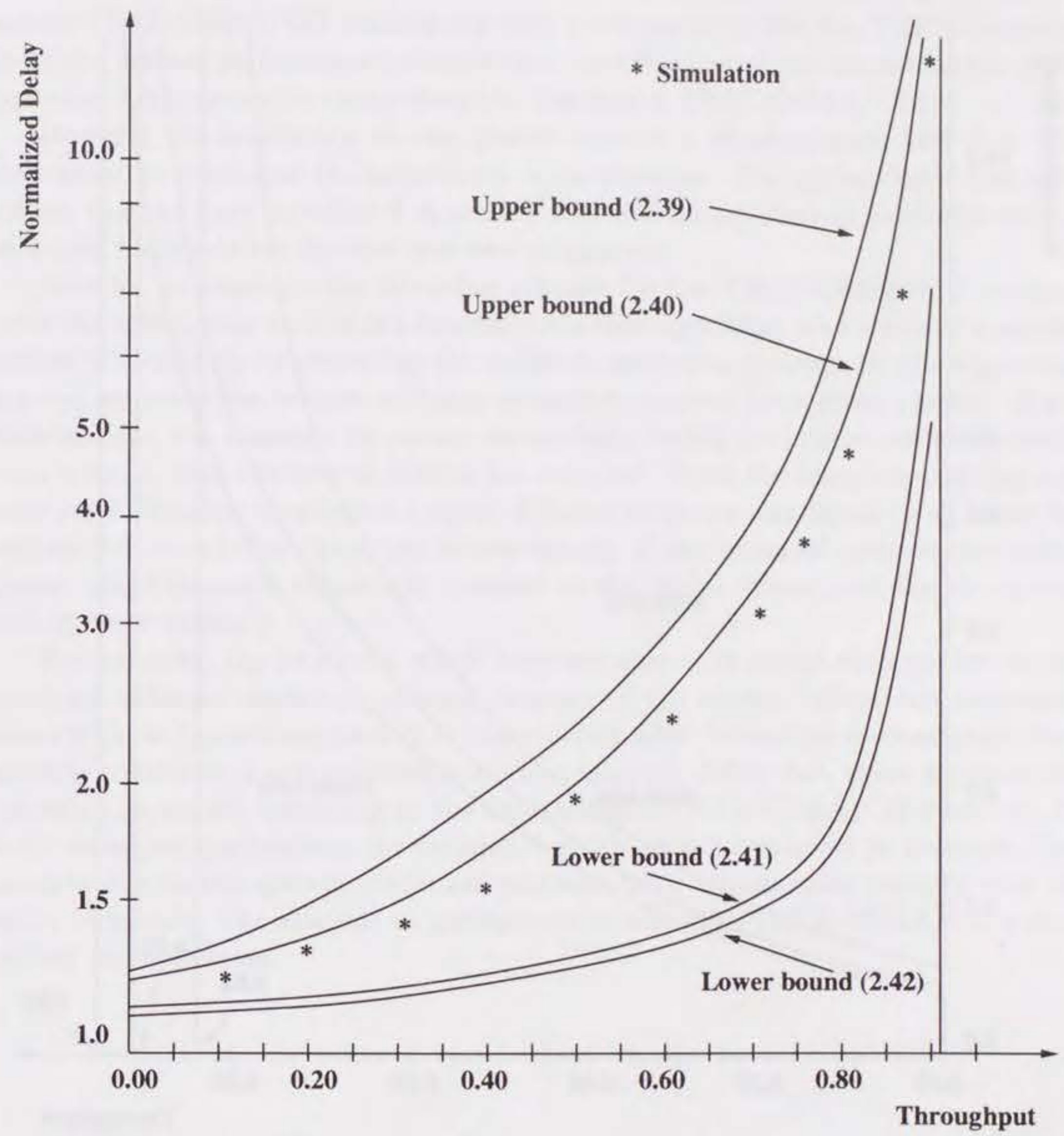

Figure 2.10: Comparison between analyses and simulation study.

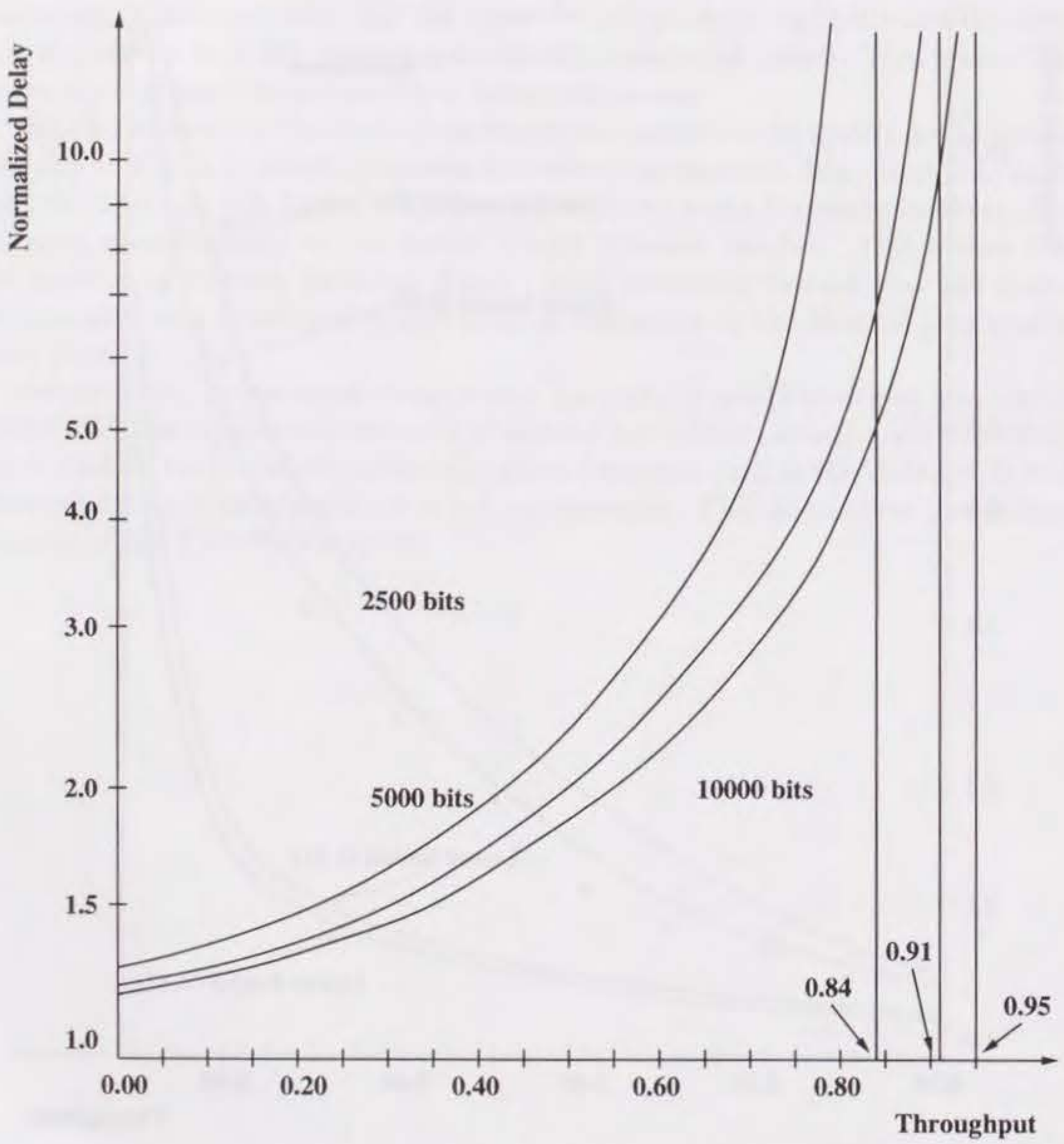

Figure 2.11: Comparison of different packet length.

2.6 Robustness of the Protocol

It has been pointed out that the tree collision resolution algorithm employing the blocked access scheme is more sensitive to the system error comparing with that using the free access scheme [Geor86, Math85]. If the system fails to detect the channel status (i.e., empty, collision, success), the continuing execution of blocked access scheme may be involved in troubles. As was shown in section 2.4, the blocked access TREE-CSMA/CD realizes the very good property like the FCFS discipline, from the system performance point of view, and its algorithmic manipulation in the practical LAN system is easier than the free access TREE-CSMA/CD.

However, its sensitivity to the system error is a disadvantage, and it is very important to guarantee the robustness of the protocol. The probabilistic tree algorithm, that we have introduced in section 2.2, uses binary random numbers and the colliding terminals are divided into two subgroups.

Now let us consider the following scheme for the TREE-CSMA/CD to equip with the robustness; that is the deterministic tree algorithm, which uses the address values of terminals for executing the collision resolution process. In this algorithm, we can estimate the longest collision resolution interval for a given system. If any terminal can not transmit its packet successfully within the longest collision resolution interval, that the system failure has occurred. Then the terminal noticing such abnormal situation broadcasts a signal different from the jam signal to all other terminals (let us call this signal the failure signal). If any terminal receives this failure signal, all of its stack values are updated to the initial values, and the the system will operate normally.

Furthermore, the terminals which were not able to transmit their packets in the previous collision resolution interval because of the system failure can retransmit them without the waiting time of N immediately after the system recovery, and these packets constitute a new collision resolution interval. After that, every terminal will transmit its packet according to the deterministic TREE-CSMA/CD protocol. By such an access mechanism, the terminals which were interrupted to transmit their packets due to the system errors are provided with transmission priority over the other terminals. The above is an outline how to make the TREE-CSMA/CD a more robust access scheme.

2.7 Priority Function

Our proposed blocked access TREE-CSMA/CD protocol can easily take in a packet based prioritized transmission mechanism. As stated in section 2.2, the TREE-CSMA/CD protocol requires an idle time interval N for recognizing the beginning of a new collision resolution interval.

For realizing a packet based priority function, we can efficiently utilize this idle time interval N. That is, the terminal with the highest prioritized packet uses this idle time interval N, and the terminal with the second highest prioritized packet employs an idle time interval longer than N, i.e., $N + 2\tau$, and further this idle time interval increases by 2τ as the priority level of packet becomes lower by one, respectively. Using such variable idle time intervals, if a terminal with lower prioritized packet detects the carrier in the channel within the idle time interval defined for its priority, then the terminal is prohibited to transmit its packet in the next collision resolution interval and it waits for the next idle time interval by sensing the channel. The terminal's waiting state is continued until it can transmit its packet in a certain idle time interval whose time length is for the priority level of its packet.

Using variable channel sensing time in the idle time interval between two successive collision resolution intervals, we can easily realize a packet based prioritized TREE-CSMA/CD protocol as explained above. In the blocked access scheme, the above prioritized access scheme forces lower prioritized packets to have longer access waiting time, and it results in smaller multiplicity of the initial collision of a collision resolution interval as compared with the protocol without the prioritized mechanism. This makes the system more stable and validate the soundness of proposed prioritized mechanism of the TREE-CSMA/CD.

2.8 Conclusion

We proposed a CSMA/CD protocol employing the blocked access tree collision resolution algorithm as its back-off algorithm, and evaluated its performance. We have demonstrated the following good properties of TREE-CSMA/CD.

1. Very high stability of the TREE-CSMA/CD as compared with the CSMA/CD employing conventional back-off algorithms. In particular, no bistable behavior of the mean delay versus throughput performance is shown in the TREE-CSMA/CD and the FCFS discipline is realized because of the blocked access scheme.

2. The TREE-CSMA/CD realizes a similar system performance as that of the CSMA/CD with an optimal back-off algorithm (OPA) which ideally has the capability to recognize the number of terminals with transmitting packets. This gives a proof that the TREE-CSMA/CD employs a very efficient feedback mechanism of the channel information.

3. A robust scheme and a prioritized mechanism can be easily implemented utilizing the access mechanism of the TREE-CSMA/CD protocol.

To improve the system performance of the TREE-CSMA/CD protocol, it is possible to employ, e.g., the ITA (Improved Tree Algorithm) [Muro86a] as its collision resolution algorithm for deleting redundant empty slots. However, in LAN systems, we can not expect a remarkable performance improvement by such techniques since the length of empty slot is very small as compared with that of successful packet transmission slot, though such improving techniques make the protocol very complex. Our proposed TREE-CSMA/CD scheme, and only back-off algorithm is different from the standard one. Thus, considering its practicality, high performance, and desirable stability, the TREE-CSMA/CD is a recommendable variety of the CSMA/CD scheme in the bus type LAN.

Chapter 3

Tree Algorithms with Reservation Mechanisms

3.1 Introduction

For constructing autonomous decentralized information systems, the development of fully-distributed and effective communication protocols is one of most important research issues. Random multiple-access communication systems with the contention type channel have the feature to easily implement distributed protocols. However, collisions reduce the system performance remarkably and often make the channel state very instable by the saturation. Therefore, the most important issue in the conventional research and developments in this field has been the resolution of conflicts for efficient use of the common communication medium. Several well-known papers including [Fayo77] and [Haye78] demonstrated the inherent channel instability of the typical ALOHA type random access scheme in the absence of external control when the number of transmitters is large.

A highly effective innovation in random access schemes was introduced by Capetanakis [Cape79a, Cape79b] and Tsybakov and Mikhailov [Tsyb78] with the tree type collision resolution algorithm. Their proposed protocols have been shown to excel in channel stability (see, e.g., [Cape79a], [Cape79b], [Muro85]), and many algorithms have been investigated by numerous authors under various distributed environments of communication systems (see, e.g., [Haye78], [Kawa88a], [Moll83], [Oie86], [Tsyb82]).

Moreover, the prototypes of current information systems tend to utilize each communication medium for transmitting multifarious messages such as text, voice, or graphic images. In this situation, the types of packetized messages would vary in length and generation interval, and the requirements for transmission of each kind of messages would be different. Thus, in addition to realizing the stability of communication channels, it is important to develop transmission protocols which can reflect the requirements as well as features of the packetized messages of multifarious information media.

In this chapter, for developing the communication protocols which ensure the channel stability and are effective to transmit multifarious information media, we will discuss the tree algorithms with reservation function. Especially, based on our reservation scheme proposed in [Kawa87, Kawa92a], we will propose the tree type protocols with priority mechanisms. As the basic collision resolution algorithm of our proposing protocols, a deterministic tree algorithm (DTA) [Shim86] is employed, and our deterministic tree algorithm with message reservation will be referred to as DTA-MR.

The exact description of the DTA and the DTA-MR is presented in section 3.2. In section 3.3, after making several system assumptions for performance analysis, we show the channel throughput and approximately obtain the mean message transmission delay time. Moreover, system performance obtained by our proposed scheme is illustrated according to the numerical results. In section 3.4, we propose tree algorithms with priority mechanism based on DTA-MR. Then we discuss various properties of our proposed protocol with priority mechanism.

3.2 Procedures of DTA and DTA-MR

In this section, we will describe the usual packet transmission based tree algorithms (see, e.g., [Cape79a], [Cape79b], [Mass80], [Tsyb78]). The time span from the slot where an initial collision occurs to the slot from which all transmitters recognize that all packets involved in the above initial collision have been successfully received is called a *collision resolution interval* (or *cycle*). The collision resolution process of each cycle can be expressed by a *tree graph.*

3.2.1 Procedure of DTA using tree graph

In the DTA, each leaf corresponds to a terminal in a system and has an address with the form $a_1a_2\cdots a_m$ $(0 < a_i < Q-1,\ i = 1, 2, ..., m)$. For instance, in Fig. 3.1, the addresses of the terminals are given by $000, 001, 010, \cdots, 110$ and 111. We shall now introduce two more definitions concerning tree graphs.

- n_{ij}: an address of the j-th node (from the left) at depth i in a tree graph, where $i > 1$ (i.e.,n_{ij} is not defined for the root node of a tree graph).
- $T_{n_{ij}}$: a subtree with the root node which has the address n_{ij}.

Using Fig. 3.1, we shall give an example of the execution of the DTA. A slot in which a packet has been successfully transmitted is called a *success slot*, a slot in which a collision has occurred is called a *collision slot*, and a slot in which no packet has been transmitted is called an *empty slot*. And we shall denote collision slot by the term $\tilde{C}$-SLOT. A subtree with more than one packet corresponds to a collision slot, while a subtree with only one packet and a subtree with no packets correspond to a success slot and an empty slot, respectively. Let us consider the case that three terminals having the addresses 000, 001 and 100 are involved in a collision which occurred in the slot $\tilde{C}$-SLOT. Since the tree graph of Fig. 3.1 is a binary tree, the three terminals are divided into two subtrees, T_0 and T_1. First, the terminals which are included in subtree T_0 retransmit their packets in the slot next to $\tilde{C}$-SLOT. However, in this case, two terminals are included in subtree T_0 ; thus, a collision occurs again. Therefore, subtree T_0 is further divided into subtrees T_{00} and T_{01}. Subtree T_{00} still contains two terminals; therefore, the next slot becomes a collision slot again. According to the DTA, subtree T_{00} is further divided into two subtrees, T_{000} and T_{001}. These two subtrees respectively contain at most one terminal which is involved in the collision in $\tilde{C}$-SLOT. Therefore, the next two slots are the success slots. After transmitting these two packets, the terminals belonging to subtree T_{01} transmit their packets. However, since subtree T_{01} does not contain a terminal which was involved in the collision in $\tilde{C}$-SLOT, the following slot becomes an empty slot. After this empty slot, the terminals belonging to subtree T_1 retransmit their packets. In this example, only one terminal, that with address 100, transmits its packet and succeeds in transmitting it. Consequently it takes 7 slots to resolve the collision in Fig. 3.1 (i.e., the cycle length is 7 in this case). Fig. 3.2 illustrates the transmission process of the packets on the communication channel corresponding to the collision resolution process in Fig. 3.1.

In tree algorithms, in order for each terminal to recognize the slot for transmitting its packet, two types of parameters are prepared: global stack and local stack. The global stack is used to recognize a channel state, i.e., contention or collision resolution, and the other parameter, local stack, is for recognizing the slot in which a packet is to be transmitted (or retransmitted). The detailed stack mechanism is given in [Muro85].

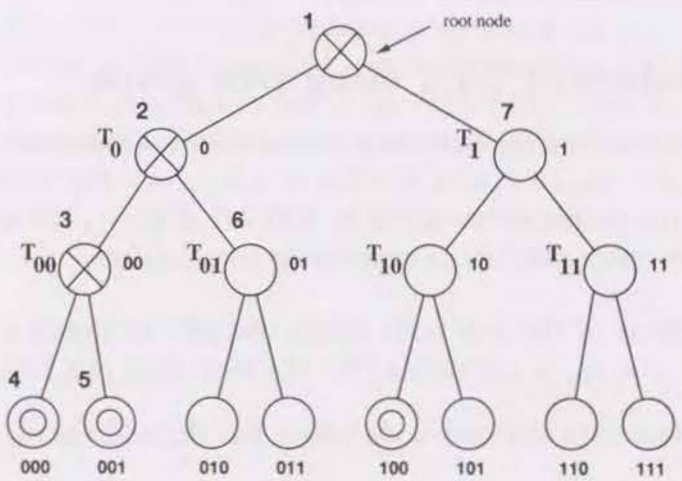

Figure 3.1: Example of a tree graph in the DTA ($Q = 2$, $m = 3$).

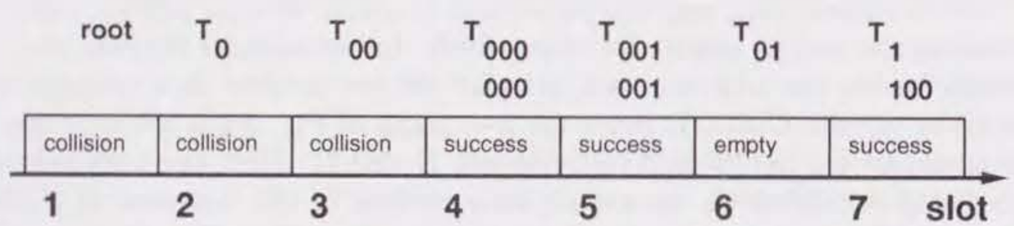

Figure 3.2: Example of collision resolution for fig.3.1.

3.2.2 Procedure of DTA-MR

Here, we consider the traffic load changing of practical communication systems. It is usual that each terminal has different traffic load and each message does not independently arrive at each terminal. Further, it is considered that most of messages construct super-messages (i.e., several messages arrive at each terminal consecutively without memoryless property). For example, voice/video packets arrive at each terminal successively during the holding time of a virtual circuit, and very long message will be divided into several short messages, and furthermore the clusters of data for process control are transmitted at the time when the system control

parameters change drastically in a short time. Thus, if we intend to develop the random multiple-access schemes useful to the practical communication systems, it is necessary to consider the algorithms applicable to the systems with super message based traffic arrival.

We can fully utilize the information obtained from the successful packets for reducing the redundant collisions in the message based transmission. In order to realize such scheme, we proposed the tree algorithms with message reservation in [Kawa87].

In our scheme, a message arriving at a terminal which transmits a message in the i-th session has the possibility to be transmitted in the reservation sub-session of the (i+1)-st session. The slots for transmitting this message in the reservation sub-session of the (i+1)-st session is reserved by the tail (or last) successful packet of the message transmitted from the same terminal in the reservation sub-session or conflict sub-session of the i-th session. Fig. 3.3 shows the collision resolution tree graph of the DTA-MR, and Fig. 3.4 shows the transmission process of messages on the communication channel corresponding to the collision resolution tree graph shown in Fig. 3.3.

3.3 Performance Analysis of the DTA-MR

In this section, we will simply show the analytical model and characteristics of our proposed protocol DTA-MR. In detail, our previous work [Kawa92a] shows the equations except of the maximum message transmission delay time.

3.3.1 Model

Let us make the following assumptions on the system model used for our performance analysis of the DTA-MR.

1. There exist Q^m ($Q \geq 2$, $m \geq 1$) terminals in the system.

2. One message consists of multiple packets. We assume for simplicity of analysis that every message consists of average p (≥ 1) packets. This p is the parameter in the geometric distribution.

3. All terminals are synchronized and forced to start the transmission of a packet at the beginning of a slot.

4. All terminals collectively form an independent Poisson source, and the messages are assumed to be generated according to the mutually independent Poisson process [Klei75]. We use (messages/slot) to denote the total average message arrival rate in a slot (i.e., λ/Q^m (messages/slot) is the average message arrival rate at a terminal in a slot); this is the parameter in the Poisson process.

5. There are no transmission errors except that resulting from collision.

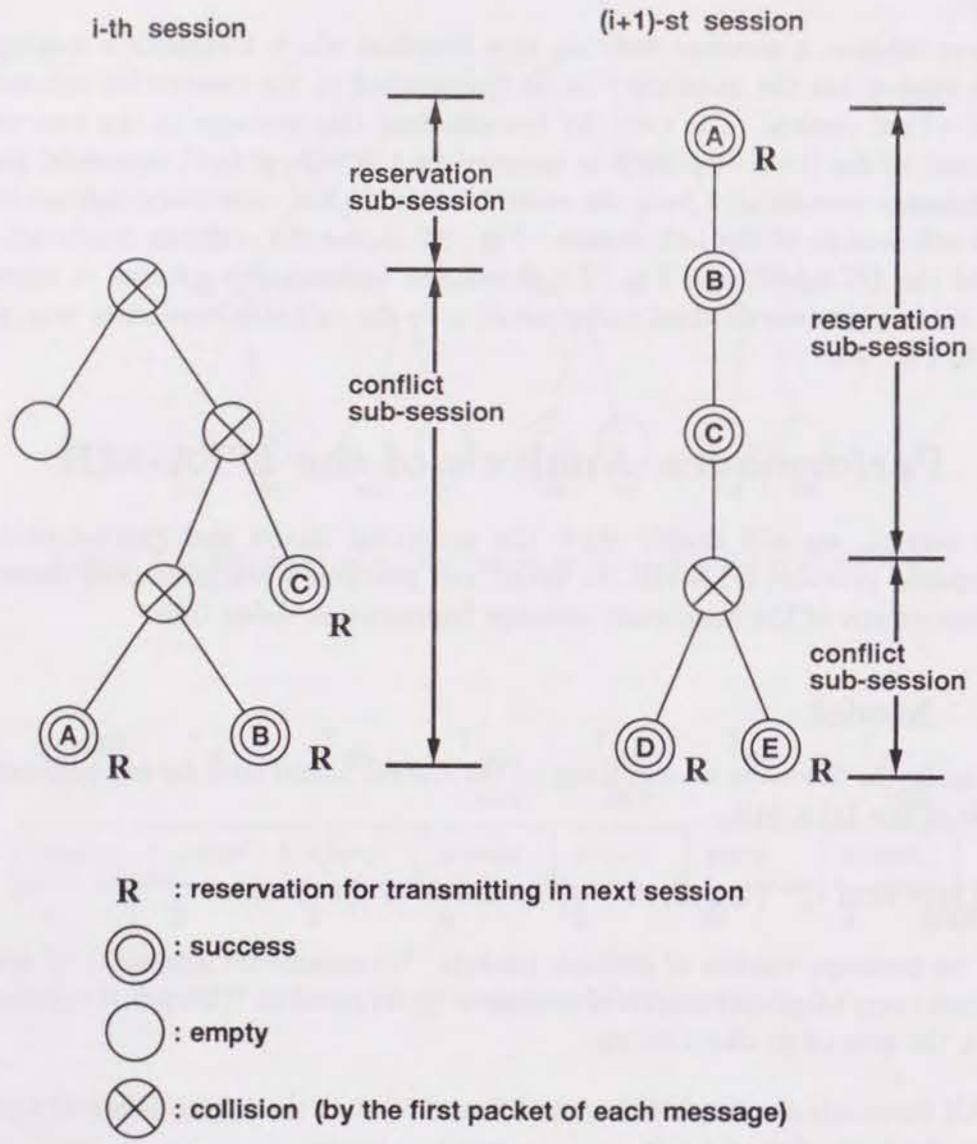

Figure 3.3: Example of collision resolution tree graph in the DTA-MR.

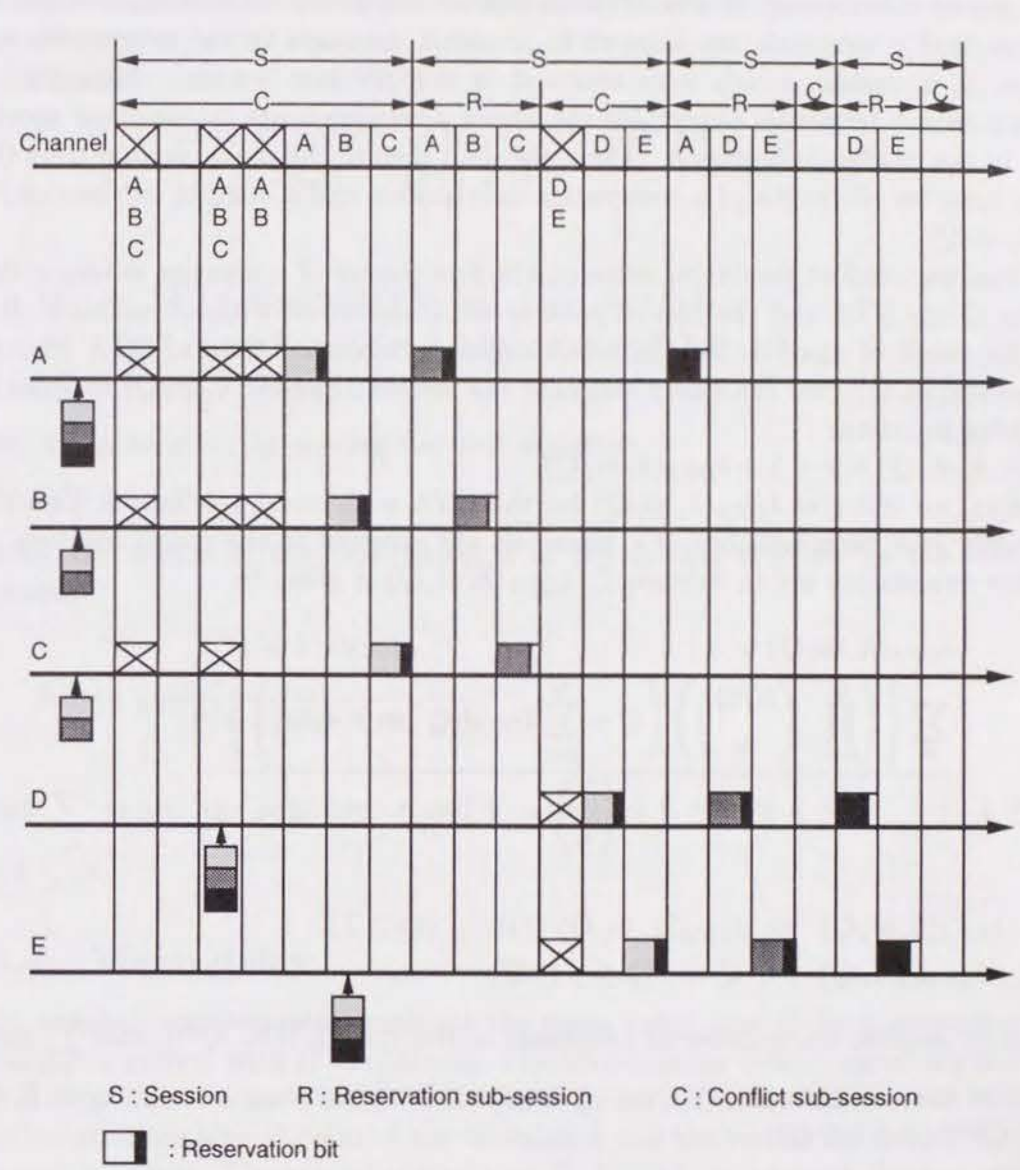

Figure 3.4: A snapshot of collision resolution in the DTA-MR.

6. Extending the modified one packet buffer model of Capetanakis [Cape79a, Cape79b], we use the modified one message buffer system [Kawa92a] for realizing the blocked access scheme.

3.3.2 Mean length of a session time

One session is composed of a reservation sub-session and a conflict sub-session. We assume that r terminals are allowed to transmit messages in the reservation sub-session in a session, which were reserved in the previous session. Moreover, we assume that k terminals except for the above r terminals are transmitted successfully in the conflict sub-session. Then, we shall denote the mean session time (i.e., mean time for all length of a reservation sub-session and a conflict sub-session) by $t(r, k, m, Q)$.

From our conflict resolution scheme, the first packet of a message is transmitted by the Q-ary DTA and the rest of packets are transmitted without collision. If we use the result of analysis for the mean collision resolution time of DTA (denoted by $t_{DTA}(k, m, Q)$), we can easily estimate the session time $t(r, k, m, Q)$ satisfies the following equation:

$t(r, k, m, Q) = r + 1 + t_{DTA}(k, m, Q)$.

Next, we will give $t_{DTA}(k, m, Q)$ for the DTA with serial tree search algorithm [Shim86]. If n_i terminals out of k terminals are involved in the initial collision of a conflict sub-session are in subtree T_i, $t_{DTA}(k, m, Q)$ is given by

$$t_{DTA}(k, m, Q) = \frac{\sum_{\sigma}\left\{\left(\prod_{i=1}^{Q}\binom{N/Q}{n_i}\right)\left(Q+\sum_{j=1}^{Q} t_{DTA}(n_j, m-1, Q)\right)\right\}}{\binom{N}{k}}$$

$$\begin{aligned} t_{DTA}(0, m, Q) &= t_{DTA}(1, m, Q) = 0 \qquad (m \geq 1) \\ t_{DTA}(j, 1, Q) &= Q \qquad (2 \leq j \leq Q) \end{aligned}$$

where N denotes the number of terminals in the system (i.e., Q^m), and $\sum_{\sigma}$ means the sum over all Q-tuples $(n_1, n_2, \cdots, n_Q)$ satisfying $n_1 + n_2 + \cdots + n_Q = k$, $0 \leq n_i \leq Q^{m-1}(1 \leq i \leq Q)$.

3.3.3 Analysis of throughput

From the above-mentioned assumption of our system model, we can define the imbedded Markov chain [Klei75] as the number of new messages at the time when a session terminates (or a session starts). Now we shall introduce the following probability for the system withQ^m terminals:

$P(s, r, k, m, Q)$: the probability that the length of session time is s (slots) in the case that the number of reservation messages is r in the reservation sub-session and the multiplicity of the initial collision is k in conflict sub-session.

Furthermore, we introduce the following probability:

$P((r', k'), (r, k))$: the probability that the sum of newly arriving messages in a session is $r'+k'$ at the time when the session generated by the r reservation terminals and the conflict transmission of multiplicity k (terminates).

Next, we define the limiting probability of $P((r', k'), (r, k))$ as follows:

$P(r, k)$: the limiting probability that there exist r reservation messages newly reserved in a session and k conflict messages newly arrived in a session at the time when the session terminates.

Now, let us define $\mathbf{P}$ and $\mathbf{W}$ by

$$\begin{aligned} \mathbf{P} &= (P(0,0), P(1,0), \cdots, P(N,0), \cdots, P(0,i), P(1,i), \\ &\quad \cdots, P(N-i,i), \cdots, P(0,N)) \end{aligned}$$

$$\begin{aligned} \mathbf{W} &= \{P((r', k'), (r, k)) | r = 0, 1, \cdots, N, k = 0, 1, \cdots, N, \\ &\quad N \geq r + k \geq 0, r' = 0, 1, \cdots, N, k' = 0, 1, \cdots, N, \\ &\quad N \geq r' + k' \geq 0\} \end{aligned}$$

Then it can be given by solving the next equation:

$$\mathbf{WP} = \mathbf{P}$$

Solving the vector P, the throughput S of the system is given by the following equation:

$$S = \frac{\sum_{r,k}(r+k)P(r,k)}{\sum_{r,k}[P(r,k)\cdot t(r,k,m,Q)]}$$

where $\sum_{r,k}$ means the sum over r and k satisfying $0 \leq r + k \leq N$, $0 \leq k \leq N$, $0 \leq k \leq N$.

3.3.4 Mean delay

Next, we shall approximately evaluate the mean delay time D for a message transmission in a system with Q^m terminals. The transmission delay time of any *message* A is divided into two basic components (see Fig. 3.5). The first component D_1 is the time between the arrival point of the *message* A and the end of the session in which *message* A arrives. The second component D_2 is the time between the beginning of the next session and the beginning of slot in which the first packet of *message* A is transmitted successfully.

We shall approximately obtain the mean value of the first component of the message transmission delay (denoted by D_1) by the following equation:

$$D_1 = \frac{\sum_{r',k',r,k}(r'+k')P(r,k)P((r',k'),(r,k)) \cdot \sum_{L=1}^{LMAX} d(L)P(L,r,k,m,Q)}{\sum_{r',k',r,k}(r'+k')P(r,k)P((r',k'),(r,k))}$$

$$d(L) = \frac{L}{1-\exp(-\lambda L/N)} - \frac{1}{\lambda/N}$$

where $\sum_{r',k',r,k}$ means the sum over r, k, r, k' satisfying $0 \leq r+k \leq N$, $0 \leq r' \leq r+k$, $0 \leq k' \leq N-r'$ for the upper-bound (note that the last condition becomes $0 < k' < N-r-k$ for the lower-bound) and $LMAX$ is defined as $LMAX = (Q^{m+1}-1)/(Q-1)+Q^m$.

Next, we shall estimate the second component of the mean message transmission delay time D_2 in the same way. Finally we can approximately evaluate the second component of the mean delay D (denoted by D_2) as follows:

$$D = D_1 + D_2$$

In addition to the throughput and the mean delay, the mean rejection rate R_R is given by the following equation without approximation:

$R_R = 1 - throughput/(\lambda \cdot p)$.

R_R is one of the most important parameters since we assume a finite buffer system described in assumption of the system model.

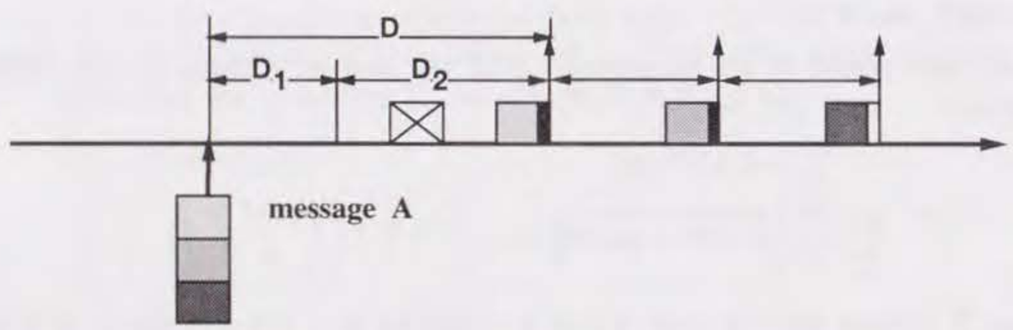

Figure 3.5: Two components of mean delay time.

3.3.5 The maximum message transmission delay time

In the practical communication systems, besides the throughput and the mean transmission delay time, it is important to guarantee the finite maximum message transmission delay time. In most of ALOHA type collision resolution algorithms, it is possible that PTAs and non-blocked TAs have infinite maximum message transmission delay time. The most desirable property of the DTA-MR is that its maximum transmission delay time is guaranteed to be finite, and this property is provided by the DTA scheme as well as the blocked access scheme. In the following, we shall evaluate the maximum message transmission delay time.

In our model for analysis, we assume the worst case of transmission delay. If all of terminals N transmit in the first slot of the conflict sub-session simultaneously, the session with this sub-session will have only the conflict sub-session. In this case, the length of the session M(N) is given by the next equation:

$M(N) = t(0, N, m, Q) = 1 + t_{DTA}(N, m, Q) + N \cdot (L_{max} - 1)$,

where $Lmax$ denotes the maximum length of messages in practical communication systems. Analytically we can estimate that L_{max} is equal to p. Since no message needs to continue to wait during two successive sessions according to blocked tree algorithms, the maximum message transmission delay time is less than $2 \cdot M(N)$. This evaluation parameter $2 \cdot M(N)$ gives very useful suggestion for designing the actual communication systems, for instance, for deciding the reasonable buffer size of each terminal.

3.3.6 Numerical results

In this subsection, the performance of our proposed scheme DTA-MR is evaluated by the numerical results obtained from the analysis. The numerical results from the simulation experiments and those from our analysis of throughput and mean message delay are given for the case $N = 8, 16$ and $p = 2$. These numerical results are illustrated in Fig. 3.6. According to the delay-throughput performance characteristics of the DTA-MR illustrated in the above figures, we do not find the undesirable property of bistability behavior (see, e.g., [Oie86]) which leads to the instability of random access protocols. This guarantees the high channel stability of our proposed scheme.

3.4 Several Transmission Protocols with Priority Mechanism

3.4.1 Internal priority in DTA-MR

In the DTA the process of resolving an collision resolution time depends completely on the address values of the terminals involved in the collision. Since each terminal has its own address, the original DTA has a priority function. If we consider the following three protocols as transmission protocols of multiple-packets in the DTA-MR, the transmission delay time of each terminal is very much influenced by the above priority function.

Type 1 (see Fig. 3.7(i)): As the most naive transmission protocol, we can employ the guard time for protecting collisions between the packets transmitted from different terminals. This algorithm is simple and realizes a very efficient use of the communication channel.

Type 2 (see Fig. 3.7(ii)): This algorithm assign is all the reserved slots periodically to the terminals which will transmit the rest of the messages. Let us refer to one round of slot assignments among the terminals as a *period*. This scheme is the most difficult to implement among the three algorithms. Especially, if every message has variable number of packets, then the manipulation of stack parameters becomes very complex. On the other hand, this scheme can provide *fairness* of transmission regarding the message transmission delay and also ensure the high probability for the reservation to transmit their next message at the reservation sub-session in the next session.

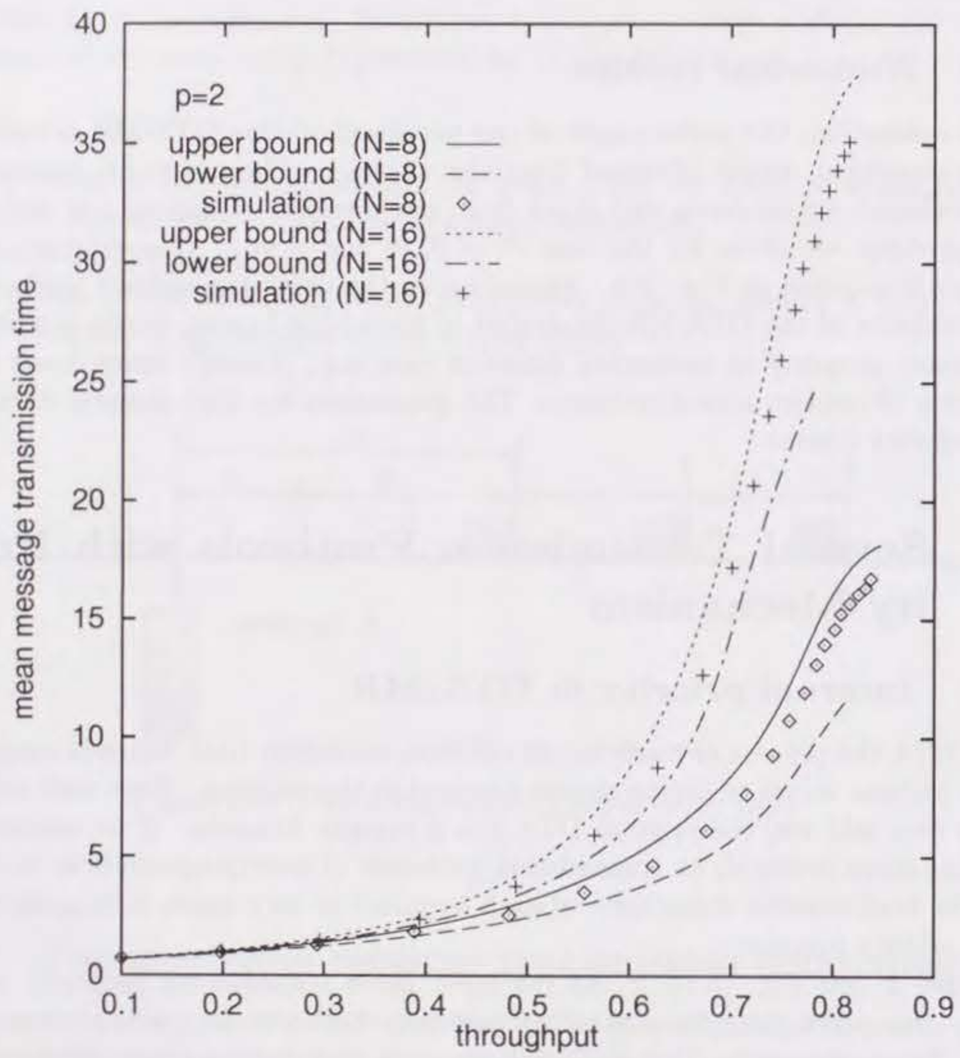

Figure 3.6: Mean message transmission time versus throughput.

Type 3 (see Fig. 3.7(iii)): This algorithm corresponds to an extreme case of the type 1 and has no guard time. If the head packet of a message is transmitted successfully, the whole rest packets of the message is transmitted just after the head packet. This scheme is applicable to the TREE-CSMA/CD [Kawa88a] with message reservation.

From the above figures of Fig. 3.7, we can obviously recognize that each terminal has the different transmission delay time according to their own addresses and transmitting sequences. Thus there exists the internal priority mechanism in the original DTA-MR. Furthermore, the integration of the above three schemes can be considered, and priority mechanisms can also be introduced with respect to the transmission slots.

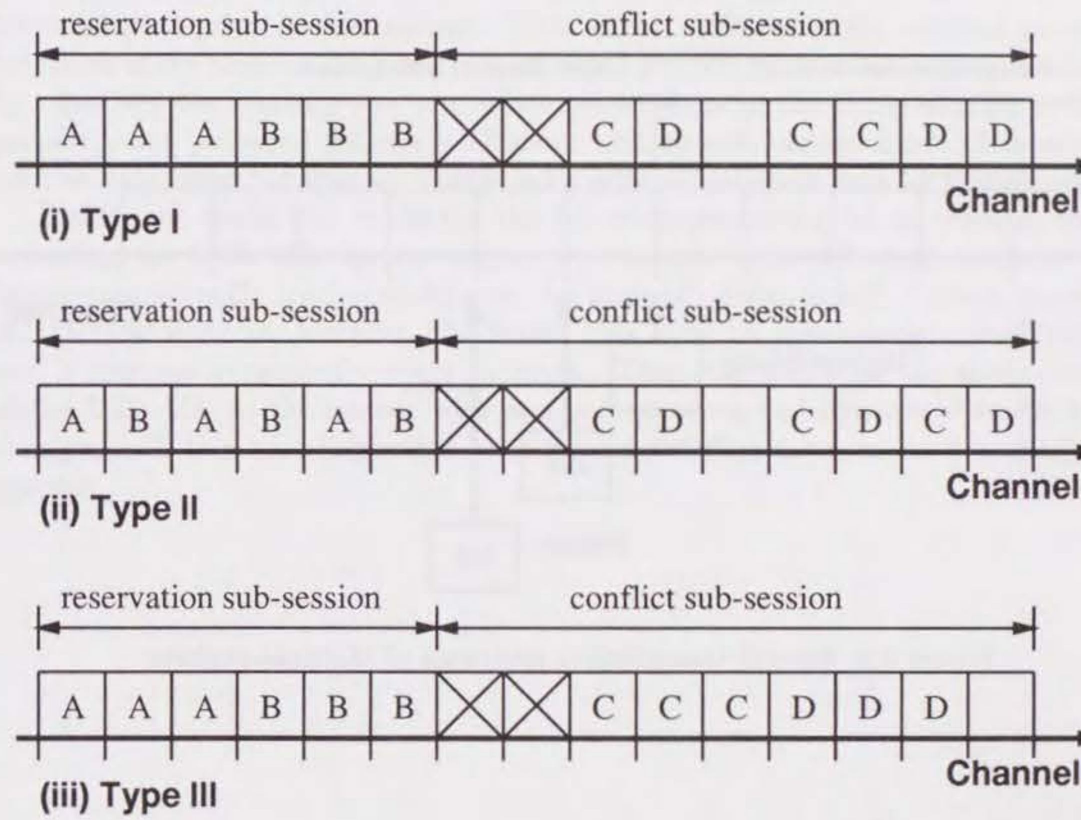

Figure 3.7: Transmission time for priority level.

3.4.2 DTA-MR with priority mechanism

In the above sections, it has been shown that the communication system employing the DTA-MR has a desirable property of channel stability even if the traffic load in the systems is very high, while the well-known ALOHA scheme provides an unstable channel state in such a channel load. However, if we use our proposed protocol DTA-MR in integrated voice/data networks, we must consider the priority function. Because the properties of voice and data messages are different regarding the transmission delay time. For example, transmission of voice packet demands a *real time* property more than reliability of transmissions, and the transmission of data demands a reliability rather than a real time property.

Now we propose the tree algorithms with priority mechanism which is based on the DTA-MR. In our scheme, at the starting slot of one conflict sub-session, which is recognized by the global stack mechanism, the messages with the highest priority can be transmitted immediately and the transmission of the rest of messages with lower priority is prohibited. If the first slot of conflict sub-session becomes empty, then at the second slot, the messages with second priority can be transmitted. Thus, according to the priority level, the starting slot of conflict sub-session is decided to realize a priority function (see Fig. 3.8).

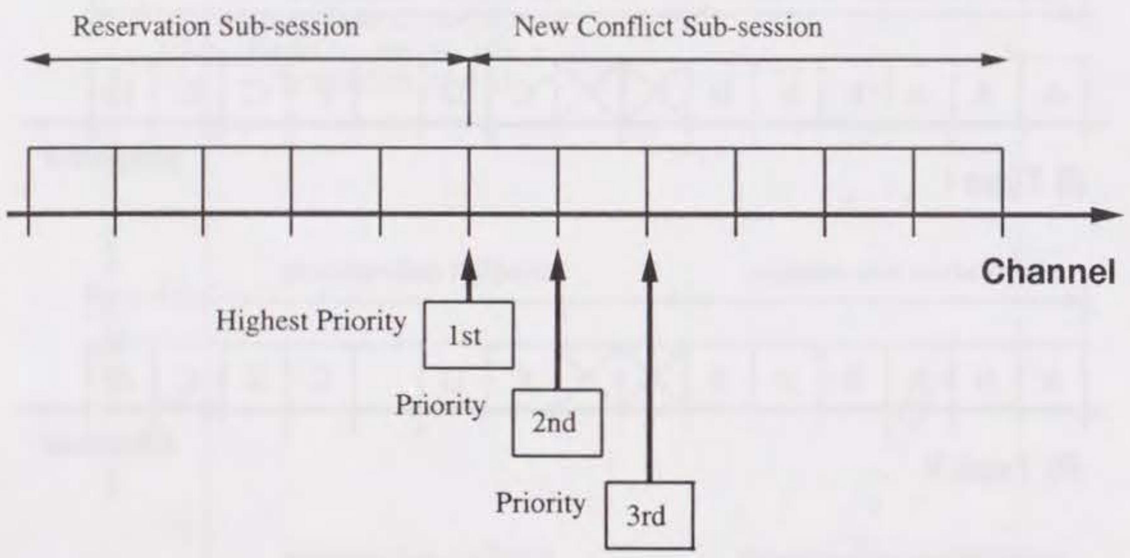

Figure 3.8: Several transmission protocols of Multiple-packets.

3.5 Conclusion

In this chapter, we proposed a random multiple-access communication system which employs the deterministic tree algorithm with message reservation (DTA-MR). An approximate analysis method of the throughput-delay performance and the maximum length of session time of the DTA-MR was presented. The obtained numerical results demonstrated that our proposed DTA-MR realizes a fully-distributed, stable and efficient multiple-packets transmission protocol using the information from successful packets. This stability property of the communication channel is considered to be very important in realizing of autonomous decentralized systems.

We extended our proposed DTA-MR and investigated the priority mechanisms using the information from the sequence of transmitting time as well as the delay of transmitting time. As a result, it became clear that the DTA-MR is very flexible for employing priority mechanisms. That is, in addition to the internal priority functions of the original DTA-MR, the external priority mechanism is easily realized by adjusting the starting slot of conflict sub-sessions in the DTA-MR. By such a property, our proposed scheme is effective to transmit various kinds of messages such as data, voice, or graphic images with different requirements for transmission.

Finally, we would like to discuss the following interesting future research topic regarding the DTA-MR. In this chapter, we assumed that all terminals have the homogeneous traffic load according to the mutually independent Poisson process. In practical systems, however, the traffic load may be non-homogeneous[Poly85] and it changes dynamically every moment. Thus, the study on the applicability of the DTA-MR to the system with non-homogeneous and dynamical traffic load changing will be a very important work for constructing autonomous decentralized systems.

Chapter 4

Control of Dynamic Environment by Knowledge Discovery and Active Database Techniques

4.1 Introduction

Natural or human-controlled processes generate huge amount of information in various kinds of large, dynamic environments. It is challenging but truly necessary to analyze the general behavior of the information flow in such dynamic environments in order to understand and/or control the environments in scientific, business and industry applications.

Modeling and management of large, dynamic environments pose new challenges and interesting research problems for data and information management systems.

First, in such a dynamic environment, data are generated rapidly, continuously, dynamically and in huge volumes. It is often unrealistic to store a *complete* set of raw data in the limited amount of memory of a database system and dynamically analyze and manage the data. This forces people either to abandon the dynamically generated, huge amount of data or to dump the generated data to tapes without timely analysis. By doing so, it is difficult to grasp the current status of a dynamic environment and react promptly to changes.

Second, most of the data/information in a dynamic environment are presented at low, primitive levels. There may not exist clear and concise relationships or regularities expressible by low level primitives. Moreover, human operators and programmers may like to analyze system conditions and express the control primitives at a relatively high level, comprehensible by human operators. There is a gap between the low-level processing data and high level control primitives.

Third, process control and system management in a dynamic environment often require *prompt*, *real-time*, and *intelligent* reactions in response to situation changes in the environment. The off-line data/pattern analysis is often too slow to meet the real time requirement. Furthermore, even if the correct patterns or regularities can be discovered, real-time decision must be made *promptly* and *automatically* in order to react correctly and timely to the changing environment.

These challenges motivate the integration of knowledge discovery and active database technologies in the following aspects.

1. *The collection of a large amount of data generated rapidly, continuously, and dynamically in an environment* can be handled by a data sampling technique which samples interesting pieces of information dynamically and systematically[Sono91].

2. *The discovery of clear and concise relationships or regularities among the collected data*, can be handled by a knowledge discovery technique which performs efficient and effective data generalization to discover useful knowledge or regularity from the collected information [Fraw91, Piat91a, Silb91].

3. *The prompt, real-time, and intelligent reactions to the changes of the environment*, can be dealt with by application of active database technology [Beer91, Geha92, McCa89] for automatic and prompt reaction and control of the environment.

In this chapter, a technique is developed for knowledge discovery in dynamic environment by extension of the attribute-oriented induction technique from relational databases[Cai91]. In order to discover the dynamic status of those systems, the cluster of actual data with dynamics is collected during the observation time using data sampling technique, and knowledge rules regarding to the status of dynamic environment are derived effectively at real time. Those discovered rules are stored in the rule base. Our proposed technique also makes new rules from the rules in the rule base during several sampling periods. The derived rules can be stored in the active database. The condition evaluator evaluates the current condition, compares it with that of the stored rules, discovers irregularities of the current status, if there exist, and executes actions to control the system.

As an example to our study, the management of interconnecting communication network using data sampling[Kawa92b], knowledge discovery[Han92], and active database techniques[Wido92] is analyzed. The status of the network changes over time, and the difficulty of effective and stable operating of the complex system is evident. In order to operate the communication network, it is essential to find the real time characteristics for *load balancing* or the *connecting status* between several network resources. We show that the machine learning technology extracts such characteristics in the network effectively, and the active database technology provides a way to control the status of the communication network.

This chapter is organized as follows. In Section 4.2, the ideas for knowledge discovery in dynamic environment are introduced, including a data sampling technique and the primitives for specification of generalization/learning tasks. In Section 4.3, an attribute-oriented induction algorithm with sampling is presented for learning several kinds of rules from a huge amount of data in a dynamic environment. The integration of knowledge discovery with active database technology is also discussed in this section. In Section 4.4, the application of knowledge discovery and active database techniques in network management is examined, and the study is summarized in Section 4.5.

4.2 Knowledge Discovery in Dynamic Environment

Before applying knowledge acquisition algorithms to the data which is generated incessantly in a dynamic environment, we should note the important difference between *scientific discovery* and *discovery in business databases* [Piat91c]. Generally, data for scientific discovery are objective and show the characteristics of natural phenomena; whereas discovery in business database reflect the real world and show the behaviors of human-artifacts. The latter one is well known as challenging and difficult problems. The volume of data in a dynamic environment could be created by artificial systems, which is similar to other business information systems. However, the huge volume of data are generated rapidly, continuously and possibly redundantly without a break in a dynamic environment. Such features are also similar to those in scientific discovery. Therefore, in order to develop the knowledge discovery in dynamic environment, it is necessary to fuse the two discovery domains. The technique of data sampling is based on the former one; whereas the technique of induction algorithm is based on the latter one.

4.2.1 Data sampling in dynamic environment

It should be noted that, even if effective algorithms are applied for knowledge discovery, it is hard to derive exact rules from all of the data via *exhaustive searches* because of the huge computation time. Moreover, in many cases only a part of data generated in a dynamic environment are actually collected. Therefore, as an approximate solution, randomly sampled data should be used in rule/knowledge discovery. To simplify our discussion, we consider several assumptions regarding to the data and learning tasks for knowledge discovery.

Assumption 1 *A set of data for a learning task is collected by random sampling from a dynamic information system or a dynamic environment.*

A set of data relevant to the learning task is collected as a subset of all the possible data generated in a dynamic environment. The following evaluation determines the suitable length of the sampling time.

For the attribute-oriented induction algorithm, our previous study in [Sono91] convinced us the accuracy of the discovered rules, including both *characteristic rules* and *classification rules*, using data sampling technique based on a statistical estimation theory. It shows the validity and credibility of knowledge discovery in database by data sampling.

The number of sampled tuples for obtaining meaningful rules in the practical sense by the attributed-oriented method is surprisingly small as compared with the number of tuples that could be generated in information system or dynamic environment. Therefore, meaningful rules satisfying the conditions can be derived within a short sampling periods.

4.2.2 Primitives for generalization specification

Without concept generalization, discovered knowledge is expressed in terms of primitive data (data stored in the databases), often in the form of functional or multi-valued dependency rules or primitive level integrity constraints. On the other hand, with concept generalization, discovered knowledge can be expressed in terms of concise, expressive and high level abstraction, in the form of generalized rules or generalized constraints, and be associated with statistical information. Obviously, it is often desirable for large databases to have rules expressed at concept levels higher than the primitive ones. Therefore, we have,

Assumption 2 *Generalized rules are expressed in terms of high level concepts.*

Ordinary unstructured numerical and non-numerical attributes are the most popularly and commonly encountered attributes in data. Generalization on non-numerical values may rely on the available concept hierarchies specified by information system designers, domain experts or users. Concept hierarchies represent necessary background knowledge which directs the generalization process. Different levels of concepts are often organized into a taxonomy of concepts. The concept taxonomy can be partially ordered according to a general-to-specific ordering. The most general concept (corresponding to *level 0*) is the null description (described by a reserved word "*ANY*"), and the most specific concepts correspond to the specific values of attributes in the database [Haus87]. Using a concept hierarchy, the rules learned can be represented in terms of generalized concepts and stated in a simple and explicit form, which is desirable to most users.

For example, the description of network domains "`kuamp.kuamp.kyoto-u.ac.jp` " can be generalized by specifying a partial order of the generalization sequence, such as "`kuamp.kyoto-u.ac.jp` $\Rightarrow$ `kyoto-u.ac.jp` $\Rightarrow$ `ac.jp` $\Rightarrow$ `jp`" in Fig. 4.1. Such a generalization sequence is obtained from a network resource illustrated in Fig. 4.2, which provides the user-/expert- specified hierarchical information. Moreover, one may specify a general rule on how to transform an internet address, such as "`134.87.61.4`", into "`deneb.cs.sfu.ca`", which is in turn transformed into a subdomain name, such as "`cs.sfu.ca`" or a department name, such as "*computing science*". Also, one may indicate that the removal of a machine name or a department name from a detail address is a step of generalization, etc.

Generalization on numerical attributes can be performed similarly but in a more automatic way by the examination of data distribution characteristics [Fish87]. It may not require any predefined concept hierarchies.

For example, we can collect the information from real interconnecting communication network by data sampling. A portion of monitoring data is shown in Fig. 4.3, where a *lnth* is a packet length, *proto* is a type of communication protocols, *source* is a source address, *destination* is a destination address, *src port* is a source port, and *dst port* is a destination port. In this example, the packet length can be generalized according to relatively uniform data distribution into several groups, such as {*below 50, 51-80, 81-100, over 100*}. Appropriate names can be assigned to the generalized numerical ranges, such as {*very short, short,* $\cdots$} by users or experts to convey more semantic meaning.

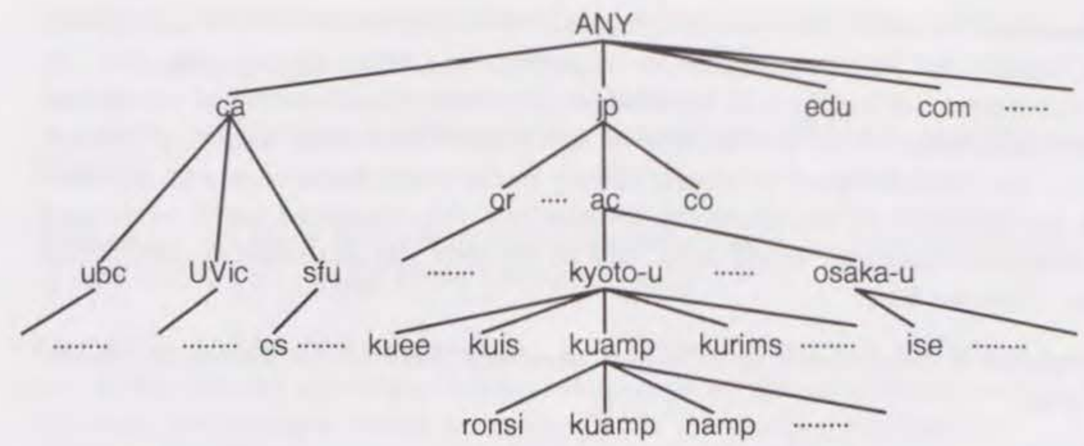

Figure 4.1: Network hierarchy provided by network resources.

Host or domain name	Internet address
cs	server = fornax.cs.sfu.ca
fornax	134.87.60.1
inazuma	134.87.62.15
fornax	134.87.60.1
arashi	134.87.62.17
asahi	134.87.62.3
perseus	134.87.62.66
menkar	134.87.62.71
mars	134.87.63.72
deneb	134.87.61.4

Figure 4.2: Hierarchical information in network resources.

lnth	proto	source	destination	src port	dst port
98	udp	130.54.20.65	130.54.20.69	983	111
60	tcp	130.54.31.98	130.54.31.97	4206	6000
60	tcp	130.54.20.192	130.54.42.1	4453	119
60	tcp	130.54.42.1	130.54.20.192	119	4453
90	udp	130.54.254.1	130.54.0.0	123	123
102	udp	130.54.28.160	130.54.0.0	513	513
88	udp	130.54.43.1	130.54.43.30	1028	53
60	tcp	130.54.28.1	130.54.31.80	4009	25
526	udp	130.54.4.2	130.54.0.0	520	520
60	tcp	130.54.43.1	134.87.61.4	23	1041
60	tcp	130.54.8.43	130.54.9.11	1023	515
...	...	...	...	...	...

Figure 4.3: Monitoring tuples from interconnecting network.

The above two generalizations may be performed with the assistance of relatively strong background knowledge (such as conceptual hierarchy information, etc.) or with little support of background knowledge. Obviously, the discovery of conceptual hierarchy information itself can be treated as a part of knowledge discovery process. However, the availability of relatively strong background knowledge not only improves the efficiency of the discovery process but also expresses user's preference for guided generalization, which may lead to efficient and desirable generalization process. Thus we have,

Assumption 3 *Background knowledge is generally available for knowledge discovery process.*

After the generalization process, the generalized relation can be transformed into a logical expression. From a logical point of view [Ullm88], each tuple in a relation is a logic formula in conjunctive normal form, and a generalized relation is a set of disjunctions of such conjunctive forms.

Following these assumptions, our mechanism for knowledge discovery in dynamic environment can be outlined as follows. First, a knowledge discovery process is initiated by a learning request, which is usually in relevance to only a subset of generating data. A data retrieval process is initiated to collect the set of relevant data using a data sampling technique. Second, generalization is performed on the set of retrieved data using the background knowledge and a set of generalization operators. Third, the generalized data is simplified and transformed into one of the following kinds of generalized rules, which may facilitate query answering and other applications.

1. **current status rules.**

   A *current status rule* summarizes the general characteristics of a set of sampled data at the present time which satisfies certain criteria, such as, the characteristics of the traffic flow on a network at the present time.

2. **stable rules.**

   A *stable rule* describes the general characteristics which remain stable over a period of time, such as, the rule that helps find out the heavy traffic on a network constantly or periodically.

3. **evolution rules.**

   An *evolution rule* describes the general characteristic of a set of patterns which evolve over several periods of sampling time, such as, how a network flow changes drastically over the past several sampling times.

4.3 Attribute-Oriented Induction in Dynamic Environment

A knowledge discovery process applies generalization operators to a large volume of sampling data and generates a set of generalized rules.

4.3.1 Basic strategies for periodical attribute-oriented induction

In general, we have the following basic techniques for attribute-oriented induction [Han92].

Technique 1 (Data focusing) *Generalization should be performed only on the set of data which are relevant to the learning request.*

Technique 2 (Attribute removal) *If there are a large set of distinct values in an attribute in the working relation, but there is no generalization operator on the attribute, the attribute should be removed from the working relation.*

Technique 3 (Attribute generalization) *If there are a large set of distinct values in an attribute in the working relation, and there exists a set of generalization operators on the attribute, a generalization operator should be selected and applied to the attribute at every step of generalization.*

As a result of generalization, different tuples may be generalized to equivalent ones where two (generalized) tuples are *equivalent*, if they have the same corresponding attribute values without considering a special internal attribute *vote*, which registers the number of tuples in the initial working relation that are generalized to the tuple in the current resulting relation. The *vote* accumulated in the generalized relation incorporates quantitative information in the learning process.

Technique 4 (Vote propagation) *The value of the vote of a tuple should be carried to its corresponding generalized tuple, and the vote should be accumulated when merging equivalent tuples in generalization.*

Technique 5 (Attribute generalization control) *Generalization on an attribute a_i is performed until the concepts in a_i has been generalized to a desired level, or the number of distinct values in a_i in the resulting relation is no greater than a prespecified (attribute generalization) threshold.*

Notice that the threshold which controls the attribute generalization is called **attribute threshold** which is usually an appropriate small number (often between 2 to 10) that can be specified explicitly by a user/expert or be built in the system as a default.

Next, a stable rule shows the constant and periodical stable pattern of characteristic rules derived from different sampled data. The vote counts in characteristic rules can be used to find the stable pattern among a set of rules. Let $r_k(t)$ be the k-th characteristic rules in the rule set derived from the sampling data at time t, and $v_k(t)$ be the vote count of $r_k(t)$, normalized by the total number of sampling tuples. The numerical sequence of $v_k(t)$ is examined in a way similar to a scientific discovery process. Since the volume of rules is also accumulated as the sampling period becomes large, it is usually assumed that the vote count is similar to the natural phenomena. Therefore, attribute-oriented induction with data sampling will be effective for rule acquisition in a dynamic environment.

Discovery of functional relationships in numerical data has been studied in the programs such as Bacon[Lang87]. Generalization (or *abstraction*) is also an essential technique in such programs to grasp the knowledge about the status of a complex system. For numerical values, aggregation of variables is based on the eigenvalues of the system matrix [Iwas88]. On the other hand, in our proposed induction algorithm, aggregation of variables is done by climbing up the conceptual hierarchy. The vote counts in the derived rule describe the characteristics of a dynamic system. Based on such values, one can derive various functional relationships depending on the abstraction level of hierarchical concepts.

To derive the functions which describe the stability or variance of a dynamic system, it is important to examine the set

$$\mathcal{V}_k = \{v_k(t_i) | t_i = t + L \cdot i, (i \geq 0)\},$$

where v_k is the vote count regarding to the k-th rule, t_i is the starting time of the i-th sampling operation, and L is the sampling period.

Generally, scientific discovery applies heuristic search in an infinite space of potential relations or, equivalently, the combination of possible functional forms, in order to find an appropriate functional property of $\mathcal{V}_k$. This strategy of infinite searching causes difficulties for function finding in the real time. However, in the most cases of finding characteristics of information flow in a dynamic environment, search is limited to several typical functions. In order to keep the system stable, the system with the characteristics of the stable functions in the long range of time must be constructed. Therefore, constant values or periodical functions play an important role in those stable systems. The dynamics of the environment must be examined according to the following four patterns.

- stable status during short periods
- evolutional status during short periods
- stable status during long periods
- evolutional status during long periods

We first examine the vote counts of a specific N-th rule only. Consider the relationship, $v_k(t) = a \cdot t^n + b$. By determining suitable candidate values for n and the short/long range of time t, one may discover the increasing/decreasing property in a set of N-th rules. Periodical property can be discovered from those values using periodical functions. Such periodic properties will be stored as stable rules in a rule base. Moreover, if the same rules are discovered during different periods, the weight of those stable rules will increase. On the other hand, if anomalous values are observed in short/long periods, evolution rules in short/long periods can be extracted based on quantitative measurements of such anomaly.

Further, several vote counts can be examined in order to derive the complex stable/evolution rules in short/long periods. A sequence of vote counts of several rules may satisfy the following equation, $y = f(v_1(t), v_2(t), \ldots, v_i(t), \ldots, v_M(t))$, the way to derive rules is similar to the above method. However, the search space will become huge depending on the abstraction level when the number of rules increases.

Technique 6 (Stability Criterion) *If the sequence of vote counts $v_k(t)$ satisfy the stable condition, the rule $r_k(t)$ should be stored into the set of stable rules.*

On the other hand, an evolution rule presents the variance of the different sets of characteristic rules. We can derive those rules from the rule set by the following technique.

Technique 7 (Variant Criterion) *If the sequence of vote counts $v_k(t)$ satisfy the evolutional condition, the rule $r_k(t)$ should be stored into the set of evolution rules.*

Furthermore, some mathematical functions, such as weighted average, mean, sum, etc. can be applied to the sequence of $v_k(t)$, in the judgment of the above two criteria. Such mathematical functions can be considered as another kind of generalization operators.

Theorem 1 *The above seven generalization techniques are correct and necessary for the extraction of generalized rules from one or several portions of sampled data.*

Proof sketch. Technique 1 is obvious since only the task-relevant set of data need to be studied. An attribute-value pair represents a conjunct in a generalized rule, the removal of a conjunct eliminates a constraint and thus generalizes the rule. If there is a large set of distinct values in an attribute but there is no generalization operator for it, the attribute should be removed. Thus, we have Technique 2 which corresponds to the generalization rule, *dropping conditions*, in *learning-from-examples* [Diet83, Mich83]. The generalization of an attribute value using a selected generalization operator makes the object cover more cases than the original one and thus generalizes the concept. Thus, we have Technique 3 which corresponds to the generalization rule, *climbing generalization trees*, in *learning-from-examples* [Mich83]. Technique 4 is based on the merge of identical tuples. Technique 5 is based on the desirability of representation of each attribute at its desired level. Technique 6 is based on finding functions in the area of scientific discovery. Technique 7 is based on finding singular points in the area of scientific discovery. Thus, we have the theorem. □

4.3.2 Attribute-oriented induction algorithm with data sampling

The basic learning strategies discussed in the last subsection can be summarized into the following generalization algorithm which extracts generalized characteristic, stable and evolution rules from a large volume of data using sampling technique. The algorithm is an extension of the basic attribute-oriented induction algorithm [Cai91, Han91, Han92, Han93, Nish93] for learning rules in dynamic environment. Before the description of the attribute-oriented induction algorithm with random sampling, we define several sampling parameters and illustrate a set of sampling data in Fig. 4.4.

- $\mathcal{D}$: a large volume of data in a dynamic environment
- t : the starting time of sampling operation

- ℓ : the length of sampling time
- L : sampling period
- d : sampling density
- $\mathcal{T}$: sampled data from a large volume of data in dynamic environment with t, ℓ and d
- a_i : the i-th attribute in relational data
- v_k : vote counts regarding to the k-th rules

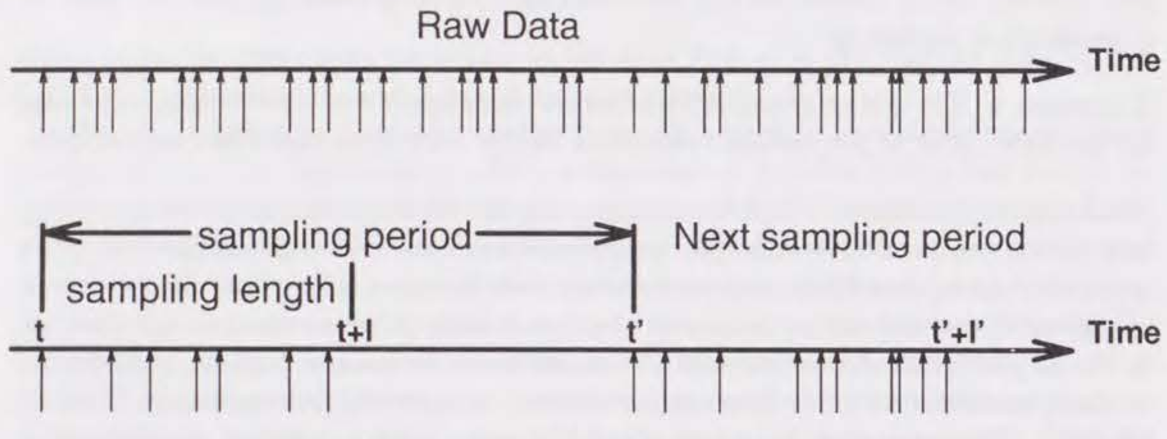

Figure 4.4: Sampling period and sampling length.

Algorithm 1 Attribute-oriented induction with random sampling in a dynamic environment

Discovery of a set of generalized characteristic, stable and evolution rules in a dynamic environment based on a user's learning request.

Input: *(i) A large volume of data in dynamic environment $\mathcal{D}$, (ii) a set of concept hierarchies or generalization operators on attributes a_i, and (iii) T, a relation threshold, and T_i, a set of attribute thresholds for attributes a_i.*

Output: *A characteristic rule, stable rule and evolution rule based on the learning request.*

Method: *Attribute-oriented induction with random sampled data with density d from the time t to $(t+\ell)$ consists of the following steps:*

Step 1. Collect a set of task-relevant sampling data $\mathcal{T}$ into an initial relation r_0 (possibly by a relational query).

Step 2. Perform basic attribute-oriented induction on r_0 as shown below.

begin

for each *attribute a_i ($1 \leq i \leq n$) in r_0* **do** *% n: the number of attributes in r_0.*

if *a_i has not reached the desired concept level T_i* **then** *% attribute threshold control*

begin

if *a_i cannot be further generalized*

then *remove a_i* *% attribute removal*

else *generalize a_i to the (minimal) desired level;* *% concept tree ascension*

merge identical tuples *% vote propagation*

end

end. *(*Basic attribute-oriented induction*)*

Output characteristic rules and store them into the rule base.

Step 3. Based on the stability criterion, derive the stable rules by the evaluation of stored v_k regarding to characteristic rules.

Step 4. Based on the variant criterion, derive the evolution rules by the evaluation of stored v_k regarding to characteristic rules.

Step 5. Repeat the induction algorithm periodically based on the new set of sampling data in the new period. □

4.3.3 Intelligent reactions to dynamic environments

Active database [McCa89, Beer91, Daya88, Geha92, Mich91, Ston91, Wido92] is one of the interesting subfields in database research. Since a dynamic environment requires prompt, real-time reaction to the changes of the environment, it is important to explore the integration of active database technology with machine learning techniques.

Fig. 4.5 illustrates an architecture of *active database* in a dynamic environment, which is conceptually divided into rule base, knowledge base and conditional evaluator. Our proposed algorithm derives characteristic rules, stable rules and evolution rules. Those derived rules should be stored in the active database selectively and be applied in the control of the environment.

To react intelligently to dynamic environments, the active database techniques and knowledge discovery processes can be integrated in the following five aspects:

1. **regularity extraction.**
2. **regularity updates.**
3. **knowledge-assisted active rule specification.**
4. **dedicated knowledge discovery.**
5. **generalized triggering.**

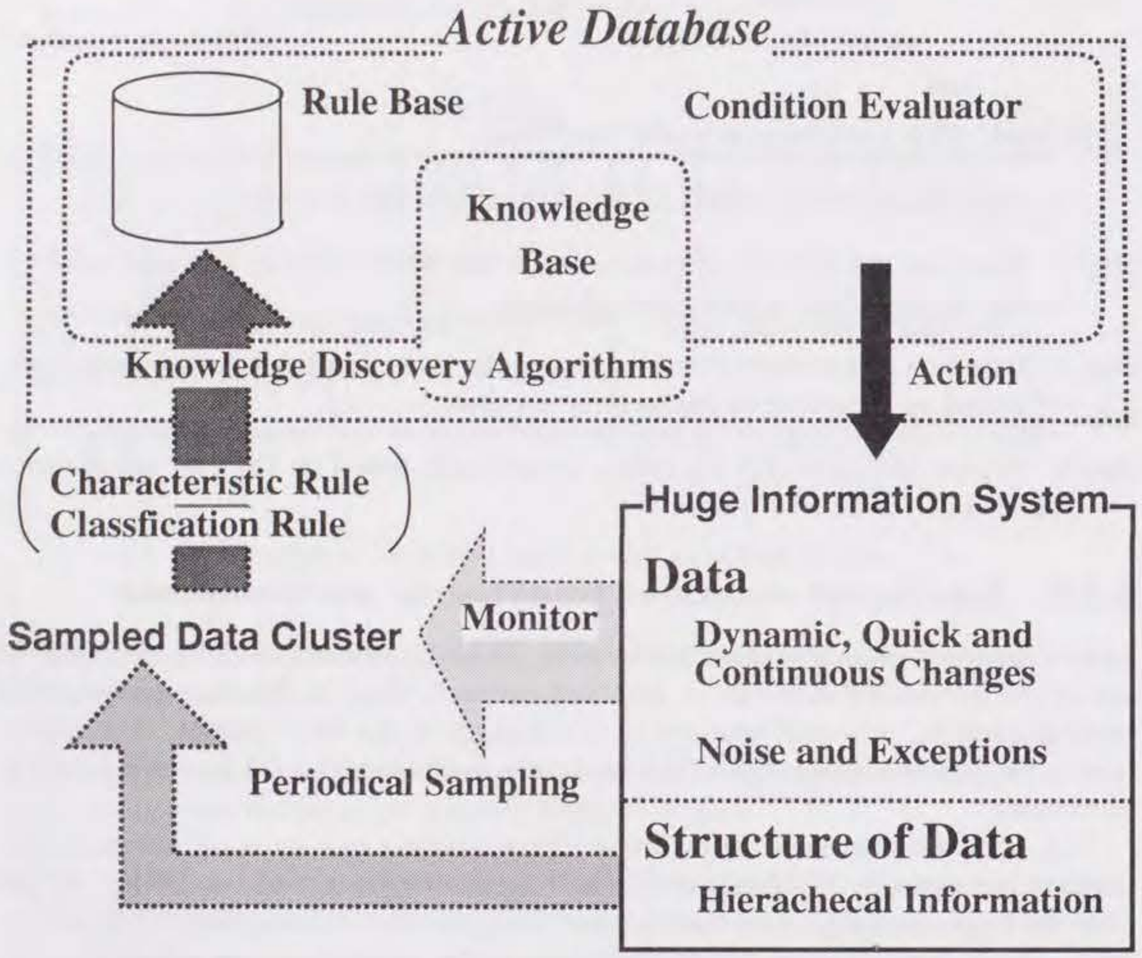

Figure 4.5: Architecture of active knowledge database in dynamic environment.

These aspects are further analyzed below.

First, regularity extraction needs the integration of both techniques. A large number of rules which summarize the current status or the stable and evolving regularities of a system can be extracted by a knowledge discovery process. However, some of these discovered regularities could be less interesting or redundant to the system. An active database method may act as knowledge discovery initiator which triggers a knowledge discovery process based on the *importance* or *freshness* of the knowledge to the system. The importance is related to some critical or sensitive aspects of an environment, such as the potential crisis of a production process, the critical condition of a chemical reaction, etc.; whereas the freshness is related to whether similar knowledge is already in the system. Furthermore, if the dynamic data is too large to be stored in a database but constantly monitoring is more preferable than data sampling, the database may store data summaries (extracted by knowledge discovery) at a level slightly higher (thus less voluminous) than the primitive data.

Second, it is important to verify, modify or invalidate the existing generalized rules stored in the rule base in a dynamic environment. Such a regularity updating task can also be performed by integration of knowledge discovery and active database technology. When a rule is discovered by a knowledge discovery process, the rule could be in one of the following cases: (1) it may enrich an existing rule by consolidating it in an extended period, or extending its condition or conclusion, (2) it may invalidate an existing rule because of the changed condition or conclusion, (3) it may not be interesting or fresh enough for inclusion in the rule base, or (4) it may violate certain integrity constraints, thus need to invoke some warning messages or perform appropriate actions. Knowledge rule verification, modification, invalidation or other appropriate actions can be specified as actions of triggers in an active database, which can be invoked when certain conditions are detected in the knowledge discovery process.

Third, the integration of the both techniques may facilitate knowledge-assisted active rule specification. It is often necessary to express active rules at the concept level higher than the primitive data in dynamic environments for comprehension and debugging by human programmers/operators. Such specification needs the help of knowledge discovery process. Moreover, the specification of appropriate conditions and actions should be based on the analysis of general characteristics in the current system, the stable and evolving regularities, and the execution history of the active rules. Obviously, such specification, refinement, and assessment of the appropriate conditions and actions of active rules need the application of knowledge discovery tools.

Fourth, dedicated knowledge discovery need the use of both knowledge discovery and active database mechanisms. In general, data sampling and knowledge discovery can be classified into *general* and *dedicated* processes. The former is adopted for *regular* environment checking and knowledge discovery; whereas the latter need to be invoked for a dedicated, detailed, frequent, and specialized data sampling knowledge discovery when certain condition happens. For example, when a production environment reaches a critical condition, an emergency data collection and knowledge discovery process should be invoked for close observation. Such an invocation of a dedicated sampling and discovery process can be performed by specifying conditions and actions for a dedicated process using the active database technology. When some unusual situation was detected by a knowledge discovery process, more focused and refined knowledge discovery can be initiated, and such a process can be refined progressively based on the discovered results. Such progressively refined processes can be specified by active database rules.

Finally, the integration may facilitate **generalized triggering**. Since the general status and evolution regularities of a system can be discovered by a knowledge discovery process and summarized at a high concept level, the conditions and appropriate actions of an active rule can be specified at a high level to communicate with both human and the system. Moreover, the actions of an active rule can also be specified at a high concept level. Appropriate mappings can be performed to transform high level actions into low level primitives to trigger the detailed actions and update the environment.

4.4 Management of Communication Networks by Knowledge Discovery

In this section, we examine the application of our discussed method to the management of an interconnecting communication network which is a typical case of dynamic environments. In an interconnecting network, there are several categories of network management problems such as *performance management*, *error recovery management*, and *topology reconfiguration*, etc. Various techniques have been proposed for network management [Covo89, Gerl91, Kawa92b, Morr91, Pan91].

In Fig. 4.6, a set of local area networks are connected via gateways, bridges, or other facilities, and these networks make one topology of physical connections. Suppose that three departments, *computing*, *information*, and *mathematics*, share these networks logically. Moreover, each network is controlled by different policies, such as machine types, network address assignment, operating system versions, administrators, and so on. Therefore, the physical connections of those networks are divided into several logical areas, as shown in Fig. 4.6, which make another logical topology. Fig. 4.6 shows both logical as well as physical topologies of networks, and these topologies act as hierarchical information. The types of multifarious messages, such as *data*, *voice*, or *graphic images*, have similar hierarchies according to their demands. For example, the transmission of voice packets demands more of the *real time* property than *reliability* (i.e., no message lost) of transmissions; whereas the transmission of control packets (e.g., acknowledging messages) demands both real time and reliability. Accordingly, in interconnecting communication networks, there exist several topologies such as physical, logical and transmission topologies.

Under this situation, the types of packetized messages transmitted through a common communication medium would vary in length and generation interval, and the requirements for transmission of each kind of messages would be different. In order to achieve such difficult as well as important network management, we have to continuously monitor the system status of different ports (stations) and layers using certain network protocols [RFC1067]. It is, however, very difficult to discover *traffic*

patterns or troubles occurred in the system from a large volume of data by human operators, since the raw information of the network are at low abstraction levels and are changing dynamically. Our proposed algorithm shows the effectiveness and flexibility at rule derivation and at the control of network status.

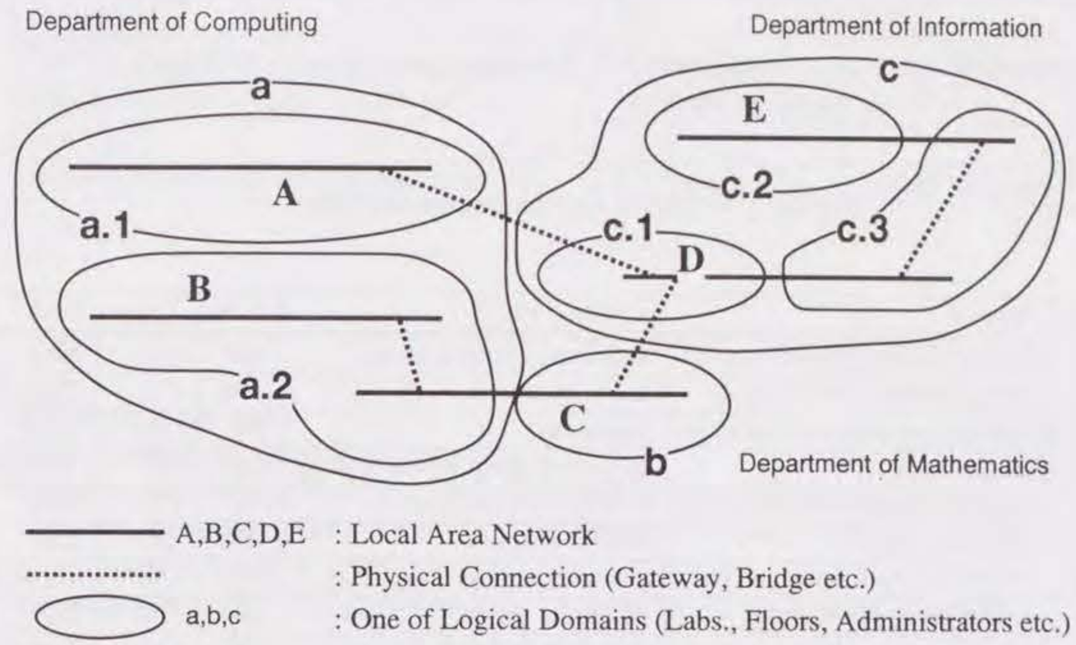

Figure 4.6: Physical and logical topology of networks.

Example 1 Suppose that a portion of the sampled data is shown in Fig. 4.3. Let the learning task be to discover a characteristic rule in relevance to *Source, Destination, Size, Type* and *Port* for those with sources in "`kuamp.kyoto-u.ac.jp`", associated with destinations out of "`kuamp.kyoto-u.ac.jp`", 300 (size) or less. The learning task can be represented in a pseudo query language in Fig. 4.7.

According to Algorithm 1, the learning request is processed as follows.

Step 1. Collect data in relevance to the learning task by data sampling and by using the information about network resources. A set of so collected information is shown in Fig. 4.8.

Step 2. Perform the basic attribute-oriented induction which derives a generalized relation, as shown in Table 4.1. The relation can also be viewed as a logic formula since both the data for learning and the rules discovered can be represented in either relational form or first-order logic rules. These rules can be stored into the rule base in Fig. 4.5.

Steps 3 & 4 & 5. After several sampling periods in Fig. 4.4, similar rules can be obtained as shown in Table 4.2. These rules can also be stored in the rule base.

At Step 3 and Step 4, using the stability criterion and the variant criterion, dynamic traffic patterns can be extracted. In this example, several interesting rules are extracted based on the difference of the feature rules: Table 4.3 is extracted by the query for a stable rule shown in Fig. 4.9, and Table 4.4 is the result for the query of a evolution rule.

```
LEARN Characteristic rule
FROM  Sampling data P
WHERE P.SourceAddress in Domain("kuamp.kyoto-u.ac.jp") and
      P.DestinationAddress not in Domain("kuamp.kyoto-u.ac.jp")
      and P.Size <= 300
IN RELEVANCE TO P.SourceAddress, P.DestinationAddress, P.Size,
                P.Type, P.Port
```

Figure 4.7: Query for characteristic rule.

Time	Source	Destination	Size	Type	Port
0.00	kuamp.kuamp.kyoto-u.ac.jp	kuis.kuis.kyoto-u.ac.jp	400	CO	Mail
0.01	ronsi.kuamp.kyoto-u.ac.jp	asahi.cs.sfu.ca	100	CO	Terminal
0.02	kuamp.kuamp.kyoto-u.ac.jp	broadcast	90	CL	Time
0.04	asahi.cs.sfu.ca	kuamp.kuamp.kyoto-u.ac.jp	80	CO	Terminal
0.05	kuamp.kuamp.kyoto-u.ac.jp	kuis.kuis.kyoto-u.ac.jp	600	CO	Mail
0.07	asahi.cs.sfu.ca	deneb.cs.sfu.ca	250	CO	File
0.09	ronsi.kuamp.kyoto-u.ac.jp	ronsi.kuamp.kyoto-u.ac.jp	120	CO	Terminal
0.10	kuis.kuis.kyoto-u.ac.jp	deneb.cs.sfu.ca	150	CO	File
0.11	kuamp.kuamp.kyoto-u.ac.jp	kuis.kuis.kyoto-u.ac.jp	30	CO	Terminal
0.12	ronsi.kuamp.kyoto-u.ac.jp	broadcast	100	CL	Logging
0.15	kuis.kuis.kyoto-u.ac.jp	kuamp.kuamp.kyoto-u.ac.jp	140	CO	Terminal
0.18	asahi.cs.sfu.ca	deneb.cs.sfu.ca	300	CO	File
...	...	...	...	...	...

```
Time: Time from starting point
Source: Source address of the packet
Destination: Destination address of the packet
Size: Packet length
Type: Connection-less or connection-oriented, etc.
Port: Purpose of communication service
```

Figure 4.8: Sampled data in a period.

Table 4.1: Rules for current status of communication network.

Source	Destination	Size	Type	Port	Vote
kuamp.kyoto-u.ac.jp	kuis.kyoto-u.ac.jp	Small	CO	Non-RealTime	354
kuamp.kyoto-u.ac.jp	cs.sfu.ca	Medium	CO	RealTime	322
...	...	...	...	...	...
kuamp.kyoto-u.ac.jp	Broadcast	Medium	CL	Non-RealTime	51

Table 4.2: Rules in other sampling period.

Source	Destination	Size	Type	Port	Vote
kuamp.kyoto-u.ac.jp	kuis.kyoto-u.ac.jp	Small	CO	Non-RealTime	682
kuamp.kyoto-u.ac.jp	cs.sfu.ca	Medium	CO	RealTime	291
...	...	...	...	...	...
kuamp.kyoto-u.ac.jp	Broadcast	Medium	CL	Non-RealTime	138

```
LEARN Stable rule
FROM  Sampling period from 1 to 100
WHERE P.SourceAddress in Domain(''kuamp.kyoto-u.ac.jp'') and
      P.DestinationAddress not in Domain(''kuamp.kyoto-u.ac.jp'')
      and P.Size <= 300
IN RELEVANCE TO P.SourceAddress, P.DestinationAddress, P.Size,
                P.Type, P.Port
```

Figure 4.9: Query for stable rule.

Table 4.3: Stable rule with periodicity.

Source	Destination	Size	Type	Port	Vote
kuamp.kyoto-u.ac.jp	kuis.kyoto-u.ac.jp	Small	CO	Non-RealTime	Periodically 15 minutes

Table 4.4: Evolution rule with unstability.

Source	Destination	Size	Type	Port	Vote
kuamp.kyoto-u.ac.jp	cs.sfu.ca	Medium	CO	RealTime	Unstable

At Step 5, the attribute-oriented induction process (with sampling) repeats periodically. □

Active database techniques can be applied to the system management based on the rules discovered in the above example. Suppose that the following definition of actions by pseudo description language, as shown in Fig. 4.10, is in the active database. The rule states that if the periodical length between different domains is less than 5 minutes, the system displays an alert message on the console, initiates the termination of connection-less packets, and checks the processes in the both domains. The descriptions of actions for evolution rules can be defined in a similar way.

Moreover, since there exist different hierarchies between physical connections and logical domains according to Fig. 4.1, different rules can be derived from the same set of raw data based on the algorithm, as shown in Table 4.5 and 4.6.

```
Event: Update Stable Rules in Rule Base

Condition: Period(P.Vote) < 5

  Query:
  SELECT P.Vote
  FROM   P Stable Rules
  WHERE  P.SourceAddress != P.DestinationAddress and P.Type=CO

Action:
  Operation: begin
               Display_Console(''code red'',Stable Rules P)
               Activate(Kill_CL in Code_Red_Rules)
               Signal(Check_Processes_in (P.SourceAddress,
                      P.DestinationAddress)
             end
```

Figure 4.10: Pseudo definition in active database.

Table 4.5: Stable rule with stability.

Source	Destination	Size	Type	Port	Vote
Mr. Lee	ANY	Large	CO	Mail	Stable

Thus, if a network protocol provides additional information regarding to the network topology, we can derive the rules about the connectivity and traffic loading among different logical domains. Moreover, these rules are also helpful for reconfiguration of the network topology by active database techniques.

Table 4.6: Stable rule.

Source	Destination	Size	Type	Port	Vote
Dept. of Computing	Dept. of Information	Large	CO	RealTime	Constantly Large

Typical examples of rules and actions are as follows:

- The connectivity between certain devices, which are administrated by Mr. Lee in network is good. If the same devices have some trouble, you should contact Mr. Lee.
- Two machines in "*Dept. of Computing*" and "*Dept. of Information*" share the same facility in the domain "*Dept. of Mathematics*" tightly. If the physical distance is short, we must connect two domains directly.

This example shows that by integration of a knowledge discovery method with an active database technology, the interconnecting network can be managed intelligently and dynamically at a high level, which may effectively control the information network across remote distance.

4.5 Conclusion

In this chapter, we studied knowledge discovery in dynamic environments. First, a cluster of data is collected by a data sampling technique. An attribute-oriented induction technique is then applied which integrates the learning-from-examples methodology with set-oriented database operations and extracts generalized data from actual data in databases. Attribute-oriented induction and data sampling substantially reduce the computational complexity of a database learning process. The attribute-oriented induction algorithm with data sampling discovers three kinds of rules: characteristic rule, stable rule and evolution rule. Moreover, using the technology of active database, generalized conditions can be evaluated and compared with the generalized rules for the control of the dynamic environment. Our study shows that the integration of attribute-oriented induction algorithm with data sampling technique and active database technology will substantially enhance the power and increase the flexibility of data and knowledge discovery and utilization in dynamic environments.

As an illustrative example, we studied the intelligent computer network management by application of the technology of knowledge discovery and active databases. By applying the proposed technique regarding to the data in a dynamic environment, the general rules which describe the traffic distribution and patterns can be summarized. Moreover, it facilitates topology reconfiguration of networks as well as the checking of the status of the machines and devices in the network.

There are many issues which should be studied further. Both data sampling and knowledge discovery processes can be triggered by active database rules. It is not clear how close interactions should be maintained between active database rules and knowledge discovery algorithms with data sampling. A tight control by active rules may restrict the possibilities of discovery of some unexpected events; however, a loose interaction may results in the discovery of a large number of uninteresting rules. The balance of different mechanisms needs much study and experiment work. We have to examine the effectiveness of the techniques developed in this chapter and implement such mechanisms in a dynamic network environment for the management.

Chapter 5

Data Mining with Composite Events Based Sampling in a Dynamic Environment

5.1 Introduction

Data mining, or knowledge discovery in databases, is the effective method to discover regularity and anomaly in the various kinds of databases[Piat91a, Han93, Ston93, Hols94, Han94, Nish93]. Especially, in scientific and business applications, such as a communication network, a production process, etc., huge volume of data is generated rapidly and continuously, and stored into management database in those complex systems. In order to control a complex system, it is important to discover the useful rules and meaningful knowledge from the primitive data in the management database.

In order to grasp the higher level knowledge, it is very effective to adopt attribute oriented induction algorithm[Cai91, Han92] with concept generalization as background knowledge. Discovered knowledge by this induction algorithm can be also associated with statistical information. Obviously, it is often desirable to derive rules expressed at higher abstract level than the primitive ones. The attribute oriented induction algorithm also decrease the computational complexity of a database learning process.

Next, it should be noted that, it is often unrealistic to analyze a complete set of primitive data even in the limited amount of memory in a database system. Then, in our previous studies[Kawa91, Kawa94b], we proposed that the integration of attribute oriented induction algorithm with data periodical sampling technique. And our previous proposed algorithm discovers three kinds of interesting rules: characteristic rule, stable rule and evolution rule[Kawa94b]. However, if effective algorithms are applied to data mining, it is impossible to derive exact rules from all of the sampled data. It is difficult to detect the relationship of continuous events in different samples, when we adopt simple periodical sampling algorithm. Our proposed algorithm with intermittent sampling periods decrease the correctness of derived knowledge.

If we would like to derive more concise knowledge from the several clusters of sampled data in a dynamic system, it is effective to change the sampling length depending on the sequences including specific events/data and so on. Then, it is also necessary to develop the biased sampling technique in order to observe sequences of events/data in a dynamic system.

In this chapter, we focus on the technique of composite events detection in active database[Geha92, Chak94], it offers the prompt, real-time, and intelligent reactions to the complicated sequences of events. We propose the sampling technique based on the occurrences of composite events detection instead of periodical sampling method. When we focus on the specific sequences or occurrences of composite events/data, it should be possible to increase the correctness of rules derived from the same number of tuples in data. In order to develop biased sampling technique based on composite events/data detection, we examine the four semantics of composite events using the notion of a global event history[Chak94]. In recent, chronicle, continuous and cumulative contexts, several combinations of the initiating events and terminating events are detected.

Using several contexts, we evaluated the performance of the sampling method based on composite events detection. We had simulation studies on the characteristics of composite events based sampling technique in the point of required size of memory area during the execution times in mining queries. Finally, as an example of applications for data mining, intelligent management for computer communication networks is presented.

This chapter is organized as follows. In Section 5.2, the data mining technique and our previous results for knowledge discovery with data sampling are introduced. In Section 5.3, we discuss the management of an interconnecting communication network which is a typical case of dynamic environments. In Section 5.4, composite events detection for several kinds of contexts is presented. The integration of data mining with active database technology is also discussed in this section. In Section 5.4.1, the effectiveness of data sampling based on composite events is presented by simulation studies. In Section 5.5, one of applications in data mining and active database techniques for network management is explained, and the study is summarized in Section 5.6.

5.2 Data Mining

5.2.1 Knowledge discovery in databases

Knowledge discovery technologies for mining rules or patterns in Very Large Databases (VLDB) are very important for developing the next generation intelligent database systems[Pars89]. The number of stored tuples or instances in VLDB becomes several millions or billions. As the size of primitive instances becomes large, the number of rules or regularities embedded in such instances potentially increases.

In order to discover rules, techniques of machine learning[Mich83] are applicable to data mining, but we have to consider other constraints which have not been employed in the area of knowledge acquisition in machine learning. This is due to the reason that the database usually stores facts of only positive set, though we derive rules from the positive as well as negative set in almost cases of learning-from-examples. Thus, we have to avoid the over-generalization for deriving rules certainly from the facts of positive set, moreover it is required to discover the following valuable and useful constraints at the data mining phase.

- Dependencies among attributes.
- Hierarchical structure among attribute-values.
- Inclusion relationship among attribute-values.

There are two types of data mining algorithms utilizing constraints described at the stage of constructing databases. One is the tuple oriented method which makes use of the dependencies of each attribute in relational databases[Piat89, Piat91b]. Without concept generalization, discovered knowledge is expressed in terms of primitive data (data stored in the databases), often in the form of functional or multi-valued dependency rules or primitive level integrity constraints. The other is the attribute oriented induction method which utilizes the conceptual hierarchy of attribute values[Cai91, Han93].

In this chapter, we will adopt attribute oriented induction method with concept generalization. Discovered knowledge can be expressed in terms of concise, expressive and high level abstraction, in the form of generalized rules or generalized constraints, and be associated with statistical information. Obviously, it is often desirable for large databases to have rules expressed at concept levels higher than the primitive ones.

Furthermore, after the generalization process, the generalized relation can be transformed into a logical expression. From a logical point of view, each tuple in a relation is a logic formula in conjunctive normal form, and a generalized relation is a set of disjunctions of such conjunctive forms. The derived rules can be represented in terms of generalized concepts and stated in a simple and explicit form, which is desirable to most users.

Moreover, we have to note that, even if we apply very effective methods in mining stage, it is very hard to derive exact rules from all stored data via exhaustive searches because of computation time. Therefore, as an approximate solution, a set of data relevant to the learning task is collected as a subset of all the possible data.

The number of sampled tuples for obtaining meaningful rules in the practical sense by the attributed oriented induction method is surprisingly small as compared with the number of tuples that could be generated in information system or dynamic environment. Therefore, meaningful rules satisfying the conditions can be derived within a short sampling periods.

5.2.2 Attribute oriented induction method with periodical sampling

Generally, we have the following basic techniques for attribute oriented induction method[Han93, Kawa94b].

1. *Data focusing*; Generalization should be performed only on the set of data which are relevant to the learning request with (or without) sampling technique.

2. *Attribute removal*; If there are a large set of distinct values in an attribute in the working relation, but there is no generalization operator on the attribute, the attribute should be removed from the working relation.

3. *Attribute generalization*; If there are a large set of distinct values in an attribute in the working relation, and there exists a set of generalization operators on the attribute, a generalization operator should be selected and applied to the attribute at every step of generalization.

4. *Attribute generalization control*; Generalization on an attribute a_i is performed until the concepts in a_i has been generalized to a desired level, or the number of distinct values in a_i in the resulting relation is no greater than a prespecified (attribute generalization) threshold.

5. *Vote propagation*;

   The value of the vote of a tuple should be carried to its corresponding generalized tuple, and the vote should be accumulated when merging equivalent tuples in generalization.

6. *Stability criterion*;

   If the sequence of vote counts $v_k(t)$ satisfies the stable condition, the rule $r_k(t)$ should be stored into the set of stable rules.

7. *Variant criterion*;

   If the sequence of vote counts $v_k(t)$ satisfies the evolutional condition, the rule $r_k(t)$ should be stored into the set of evolution rules.

Since the volume of rules is also accumulated as the sampling period becomes large, it is usually assumed that the vote count is similar to the natural phenomena. Therefore, it is possible to use scientific discovery approaches[Lang87], attribute oriented induction method with data sampling will be effective for rule acquisition

in a dynamic environment. The vote counts in characteristic rules can be used to find the stable/evolutional pattern among a set of rules.

Some mathematical functions, such as weighted average, mean, sum, etc. can be applied to the sequence of vote counts, in the judgment of the above two criteria. Such mathematical functions can be considered as another kind of generalization operators, we can derive the following three types of different rules.

1. **Current status rules;**

   A current status rule summarizes the general characteristics of a set of sampled data at the present time which satisfies certain criteria, such as, the characteristics of the traffic flow on a network at the present time.

2. **Stable rules;**

   A stable rule describes the general characteristics which remain stable over a period of time, such as, the rule that helps find out the heavy traffic on a network constantly or periodically.

3. **Evolution rules;**

   An evolution rule describes the general characteristic of a set of patterns which evolve over several periods of sampling time, such as, how a network flow changes drastically over the past several sampling length.

5.3 Knowledge Discovery in Management Information Base

In this section, we examine the application of our discussed method to the management of an interconnecting communication network which is a typical case of dynamic environments.

In an interconnecting network, various techniques have been proposed for network management [Covo89, Gerl91, Kawa92b, Morr91, Pan91], since there are several following categories of network management problems.

- Performance management
- Fault management
- Accounting management
- Configuration and name management
- Security management

In order to achieve such difficult as well as important network management, basically we have to continuously monitor the system status of different ports (stations) and layers using certain network protocols [RFC1067]. Especially, in this chapter, by using technique of knowledge discovery in the following some of actual attributes which are first collected by RMON (Remote network MONitoring), and then stored into Management Information Base (MIB), which are defined in SNMP (Simple Network Management Protocol)[Stal93].

· etherStatsIndex (5.1)
· etherStatsDataSource (5.2)
· etherStatsDropEvents (5.3)
· etherStatsOctets (5.4)
· etherStatsPkts (5.5)
· etherStatsBroadcastPkts (5.6)
· etherStatsMulticastPkts (5.7)
· etherStatsCRCAlignErrors (5.8)
· etherStatsUndersizePkts (5.9)
· etherStatsOversizePkts (5.10)
· etherStatsFragments (5.11)
· etherStatsJabbers (5.12)
· etherStatsCollisions (5.13)
· etherStatsPkts64Octets (5.14)
· etherStatsPkts65to127Octets (5.15)

· etherStatsPkts128to255Octets (5.16)
· etherStatsPkts256to511Octets (5.17)
· etherStatsPkts512to1023Octets (5.18)
· etherStatsPkts1024to1518Octets (5.19)
· ehterStatsOwner (5.20)
· etherStatsStatus (5.21)

Fig. 5.1 shows some attributes in RMON MIB, and attributes (5.3), (5.10), (5.12) have not been observed during a sampling period.

It is, however, very difficult to discover *traffic patterns* or troubles occurred in the system from a large volume of data in Fig. 5.1 by human operators, since the raw information of the network are at low abstraction levels and are changing dynamically. Our proposed algorithm shows the effectiveness and flexibility at rule derivation and at the control of network status.

First, in order to find out useful diagnosis for condition of communication systems, we demonstrate that the query based on scientific discovery is one of effective methods to discover periodical or functional rules among certain attributes and their values by the methods of scientific discovery[Lang87]. We plot statistical attribute values of total number of transmitted packets in Fig. 5.2, then it becomes possible by this illustrated graph to find periodical characteristics regarding time axis in Fig. 5.3.

Moreover, employing intelligent database queries, we can derive more accurate and sophisticated rules from several sampled clusters in the same periodical duration. We can also derive useful functional rules regarding the characteristics of throughput versus number of collisions. Using this functional rule, if we observe any attribute value in its unstable region, it is conclusive that the current situation of the network is unstable, and we need to reduce the collisions in the network.

Furthermore, if the data collected by RMON are generalized using conceptual clustering technique, then we show that, for managing the performance of network, it is easy to provide more accurate performance evaluation by analytical knowledge for the network in [Ori96].

Finally, in case that the network management is based on alarms for error recoveries, we also show that it is very effective for the alarm function in RMON protocol to employ the composite events detection technique, which has been proposed in the conventional active database systems.

```
TimeStamp=(94/06/23/00:02:20)
MeanValue=((0,4260,12,8,0,0,0,0,0,0,0,1,2,0,4,4,0))
MeanCalc=((0))
MaxValue=(((94/06/23/10:43:18,0),
(94/06/23/20:36:11,6620), (94/06/23/11:25:19,29),
(94/06/23/12:05:00,19), (94/06/23/10:43:18,0),
(94/06/23/10:43:18,0), (94/06/23/10:43:18,0),
(94/06/23/10:43:18,0), (94/06/23/10:43:18,0),
(94/06/23/10:43:18,0), (94/06/23/10:43:18,0),
(94/06/23/11:25:19,17), (94/06/23/12:45:22,5),
(94/06/23/12:04:53,3), (94/06/23/12:43:22,6),
(94/06/23/20:17:11,8), (94/06/23/10:43:18,0)))
MaxCalc=(((94/06/23/10:43:18,0)))
..........................
```

Figure 5.1: RMON data collected by SNMP equipments.

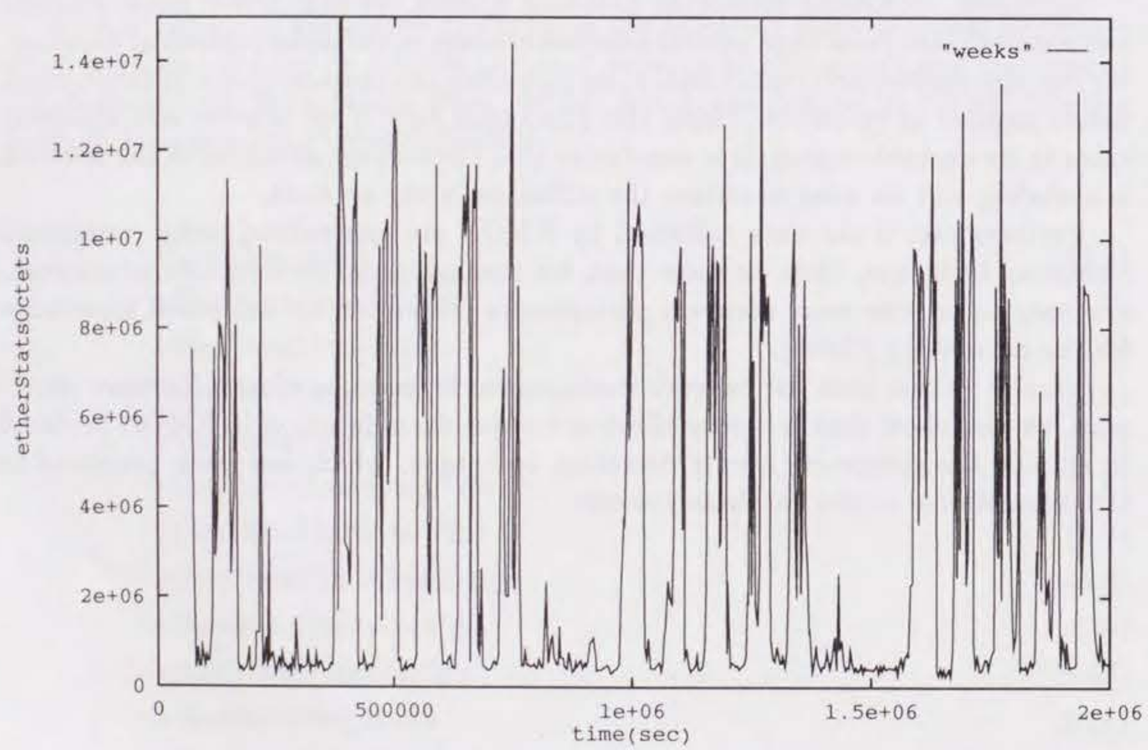

Figure 5.2: Periodicity of attribute (5.4) in a week.

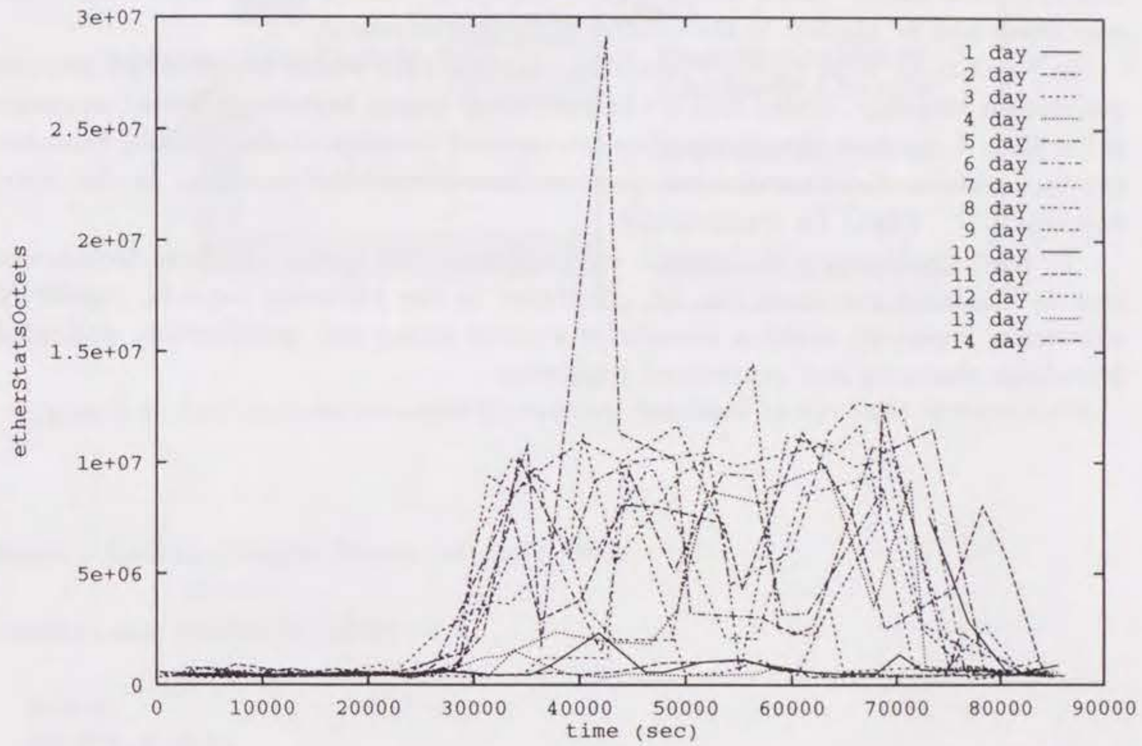

Figure 5.3: Periodicity of attribute (5.4).

5.4 Composite Events in Active Databases

Active database[McCa89, Daya88, Geha92, Wido92] is one of the interesting subfields in database research. Since a dynamic environment requires prompt, real-time reaction to the changes of the environment, it is important to explore the integration of active database technology with machine learning techniques.

5.4.1 Active database system

Fig. 5.4 illustrates an architecture of active database in a dynamic environment, which is conceptually divided into rule base, knowledge base and conditional evaluator. Attribute oriented induction method derives characteristic rules, stable rules and evolution rules. Those derived rules should be stored in the active database selectively and be applied in the control of the environment.

In Fig. 5.5, an ECA (Event/Condition/Action) rule, which is defined by pseudo description language, states that if the periodical length between different domains is less than 5 minutes, the system displays an alert message on the console, initiates the termination of connection-less packets, and checks the processes in the both domains.

To react intelligently to dynamic environments, the active database techniques and data mining processes can be integrated in the following aspects, *regularity extraction, regularity updates, knowledge-assisted active rule specification, dedicated knowledge discovery* and *generalized triggering*.

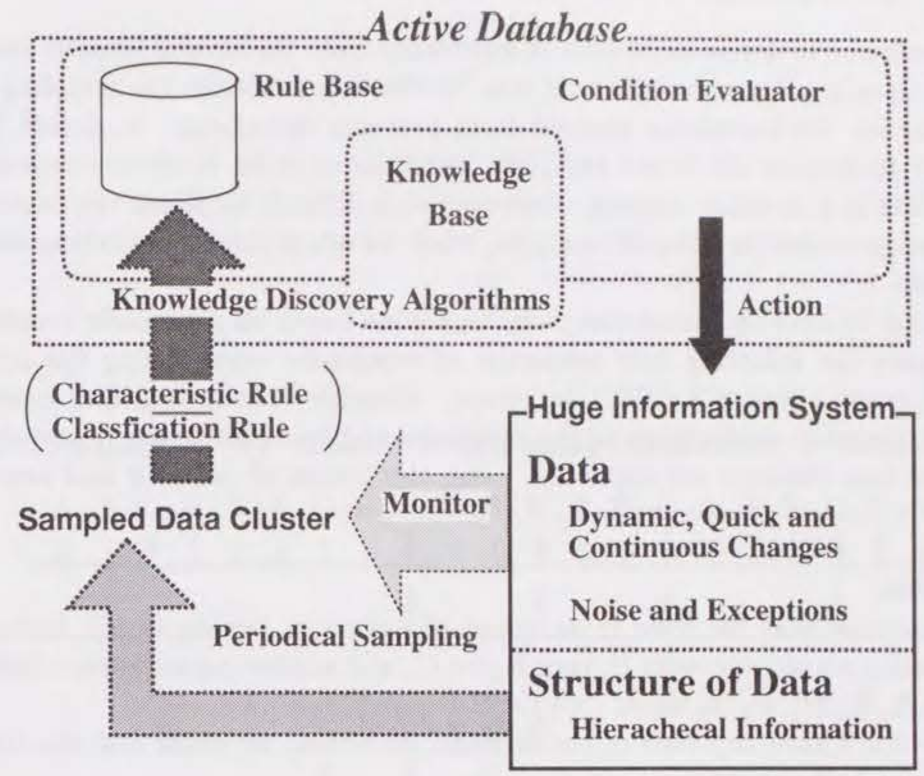

Figure 5.4: Architecture of active knowledge database in dynamic environment.

```
Event: Update Stable Rules in Rule Base

Condition: Period(P.Vote) < 5

  Query:
  SELECT P.Vote
  FROM   P Stable Rules
  WHERE  P.SourceAddress != P.DestinationAddress and P.Type=CO

Action:
  Operation: begin
               Display_Console(''code red'',Stable Rules P)
               Activate(Kill_CL in Code_Red_Rules)
               Signal(Check_Processes_in
                     (P.SourceAddress, P.DestinationAddress))
             end
```

Figure 5.5: Pseudo ECA rule definition in active database.

5.4.2 Composite events in contexts

If we would like to derive more concise knowledge from the several clusters including sampled data in a dynamic system, it may be effective to change the sampling trends depending on the knowledge derived from previous detections. It should be also necessary to develop the biased sampling technique in order to observe sequences of events/data in a dynamic system. Moreover, it is difficult to detect the relationship of continuous events in different samples, when we adopt simple periodical sampling algorithm.

In order to develop biased sampling technique based on composite events/data, we compare the following four semantics of composite events using the notion of a global event history[Chak94]. In recent, chronicle, continuous and cumulative contexts, several combinations of the initiators and terminators are detected.

These four contexts are explained using the notion of initiator and terminator events.

Examples:

Let assume that we have three types of events in mining query, initiator A, participating primitive events B, terminator C, and a following sequence of primitive events $\{A_1, A_2, B_1, B_2, C_1, A_3, C_2, C_3\}$.

If we don't have any restriction for event detection, we could find the following detections $(A; B; C)$ in the above sequence.

$$\begin{array}{llll} A_1B_1C_1 & A_1B_1C_2 & A_1B_1C_3 & A_1B_2C_1 \\ A_1B_2C_2 & A_1B_2C_3 & A_2B_1C_1 & A_2B_1C_2 \\ A_2B_1C_3 & A_2B_2C_1 & A_2B_2C_2 & A_2B_2C_3 \end{array}$$

It is evidently difficult to detect these composite events without any restrictions, we need rational and reasonable contexts. The restrictions by contexts are explained by the following sequence, and those contexts are shown in Fig. 5.6

$$\{A_1A_2C_1B_1B_2A_3C_2B_3C_3B_4B_5C_4A_4B_6C_5A_5A_6B_7C_6C_7A_7\}$$

- Recent; In this context, only the most recent occurrence of the initiator for event that has started the detection of that event is used.

  $A_3B_3C_3, A_3B_4C_4, A_3B_5C_4, A_4B_6C_5, A_6B_7C_6$

- Chronicle; In this context, for an event occurrence, the initiator, terminator pair is unique, the oldest initiator is paired with the oldest terminator for each event.

  $A_2B_1C_2, A_3B_3C_3$

- Continuous; In this context, each initiator of an event starts the detection of that event. A terminator event occurrence may detect one or more occurrences of the same event.

  $A_1B_1C_2, A_2B_1C_2, A_3B_3C_3, A_4B_6C_5, A_5B_7C_6, A_6B_7C_6$

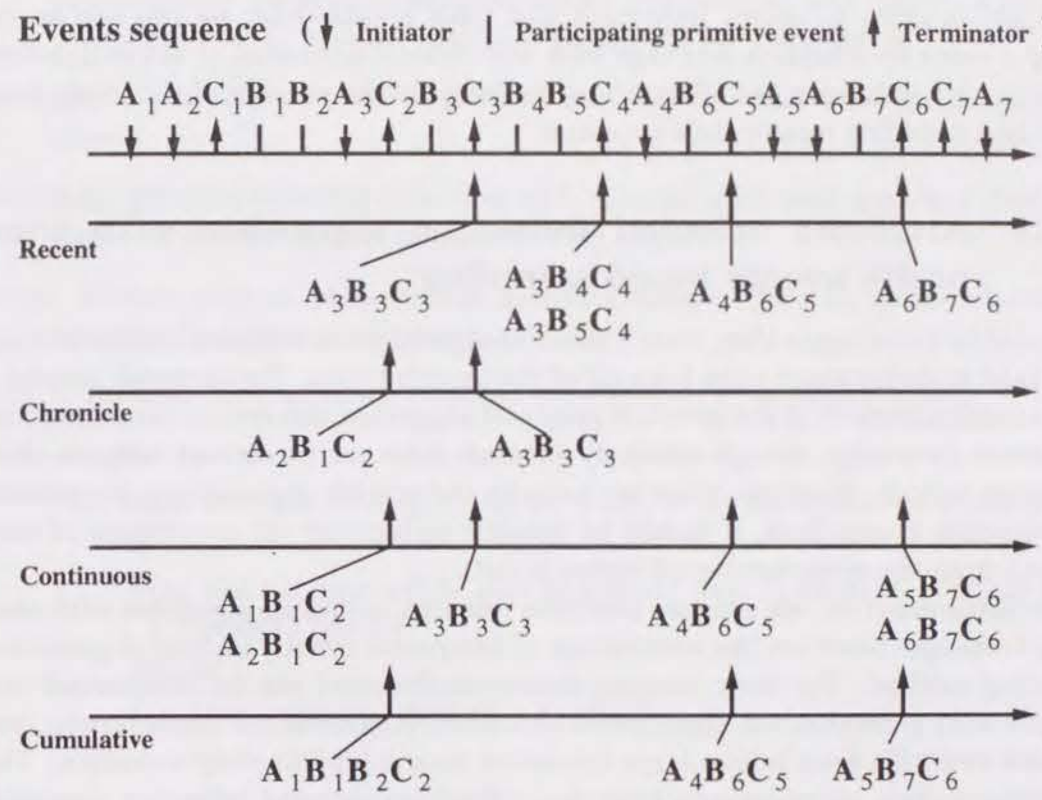

Figure 5.6: Example of composite events in four contexts.

- Cumulative; In this context, for each constituent event, all occurrences of the event are accumulated until the composite event is detected.

  $A_1B_1B_2C_2, A_4B_6C_5, A_5B_7C_6$

These four types of contexts have meaningful and helpful restriction in data mining, especially when we have to abandon or dump the observed data without analysis by something restrictions during mining process. These contexts also decrease cost of required memory in order to to activate ECA rules. Moreover, in the point of freshness of knowledge, recent context is often meaningful to control dynamic systems. In addition to these contexts, it may be useful to detect composite events over non-overlapping time intervals as periodical sampling.

Thus, in order to detect important and fresh events/data, we can use an expressive event specification language with well-defined semantics in active database systems, this technique has effectiveness to decrease the number of randomly sampled data including meaningless sequences.

5.4.3 Attribute oriented induction algorithm with composite events based sampling

It should be noted again that, even if effective algorithms are applied to data mining, it is hard to derive exact rules from all of the sampled data. Furthermore, intermittent sampling periods of our previous proposed algorithm also reduce the correctness of derived knowledge, though relatively accurate rules can be derived within a short sampling periods. However, when we focus on the specific sequences or occurrences of composite events/data, it should be possible to increase the correctness of rules derived from the same number of tuples in data.

In this subsection, we propose attribute oriented induction algorithm with sampling technique based on the occurrences of composite events, instead of periodical sampling method. The basic learning strategies discussed can be summarized into the following generalization algorithm which extracts generalized characteristic, stable and evolution rules from a large volume of data using sampling technique. This algorithm is also an extension of the basic attribute oriented induction algorithm [Cai91, Han92, Han93, Nish93].

Before the description of the attribute oriented induction algorithm with sampling based on composite events detection, we define several parameters in our algorithm.

- $\mathcal{D}$: a large volume of data in a dynamic environment
- t : the starting time of sampling operation by detecting of initiator
- ℓ : the length of sampling time determined by terminator
- L : sampling period by one pair of initiator and terminator
- d : sampling density

- $\mathcal{T}$: sampled data from a large volume of data in dynamic environment with t, ℓ and d
- a_i : the i-th attribute in relational data
- v_k : vote counts regarding to the k-th rules

Algorithm 2 *Attribute oriented induction with composite events based sampling in a dynamic environment*

Discovery of a set of generalized characteristic, stable and evolution rules in a dynamic environment based on a user's learning request.

Input: *(i) A large volume of data in dynamic environment $\mathcal{D}$, (ii) a set of concept hierarchies or generalization operators on attributes a_i, and (iii) T, a relation threshold, and T_i, a set of attribute thresholds for attributes a_i.*

Output: *A characteristic rule, stable rule and evolution rule based on the learning request.*

Method: *Attribute-oriented induction with sampled data with density d from the time t to $(t+\ell)$ consists of the following steps:*

Step 1. Collect a set of task-relevant sampling data $\mathcal{T}$ into an initial relation r_0 (possibly by a relational query).

Step 2. Perform basic attribute-oriented induction on r_0 as shown below.

begin
for each *attribute a_i ($1 \leq i \leq n$) in r_0* **do** *% n: the number of attributes in r_0.*
  if *a_i has not reached the desired concept level T_i* **then** *% attribute threshold control*
  begin
    if *a_i cannot be further generalized*
    then *remove a_i* *% attribute removal*
    else *generalize a_i to the (minimal) desired level;* *% concept tree ascension*
    merge identical tuples *% vote propagation*
  end
end. *(*Basic attribute-oriented induction*)*

Output characteristic rules and store them into the rule base.

Step 3. Based on the stability criterion, derive the stable rules by the evaluation of stored v_k regarding to characteristic rules.

Step 4. Based on the variant criterion, derive the evolution rules by the evaluation of stored v_k regarding to characteristic rules.

Step 5. Repeat the induction algorithm based on the new set of sampled data □

5.5 Simulation Study

Using several contexts, we evaluated the performance of the sampling method based on composite events detection in a dynamic environment. We had simulation studies on the characteristics of composite events sampling technique in the point of required memory area during the executing time for typical mining queries based on those contexts.

The first experiment considered mining for events, which have three different types of events, A, B, and C, we assume that each event requires same size of memory area per one detection of an event. The number of each event in this simulation is all the same. And we had the most basic detection of composite events, $(A; B; C)$. This detection is executed in four types contexts defined in previous section.

We ran 10,000 events, Fig. 5.7 shows peak values of required size of memory area for all contexts.

In Fig. 5.8, we estimated the average cost during the execution time at mining process. Fig. 5.8 shows that the average size of required memory area becomes stable quickly except chronicle context.

Moreover, in Fig. 5.9 and Fig. 5.10, we had other simulation experiments under the different condition of event B, we increase participating primitive events, which happened eighteen times in the previous simulation in Figs. 5.7 and 5.8.

These figures also shown the same kinds of characteristics in four contexts. But, the peak values are slightly different as increasing the number of participating primitive events.

When we have typical data mining queries in a dynamic environment, our simulation study shows that we should adopt the sampling methods based on the occurrences of events/data in recent context.

Our study shows that the integration of attribute-oriented induction algorithm with data sampling technique and active database technology will substantially enhance the power and increase the flexibility of data and knowledge discovery and utilization in dynamic environments.

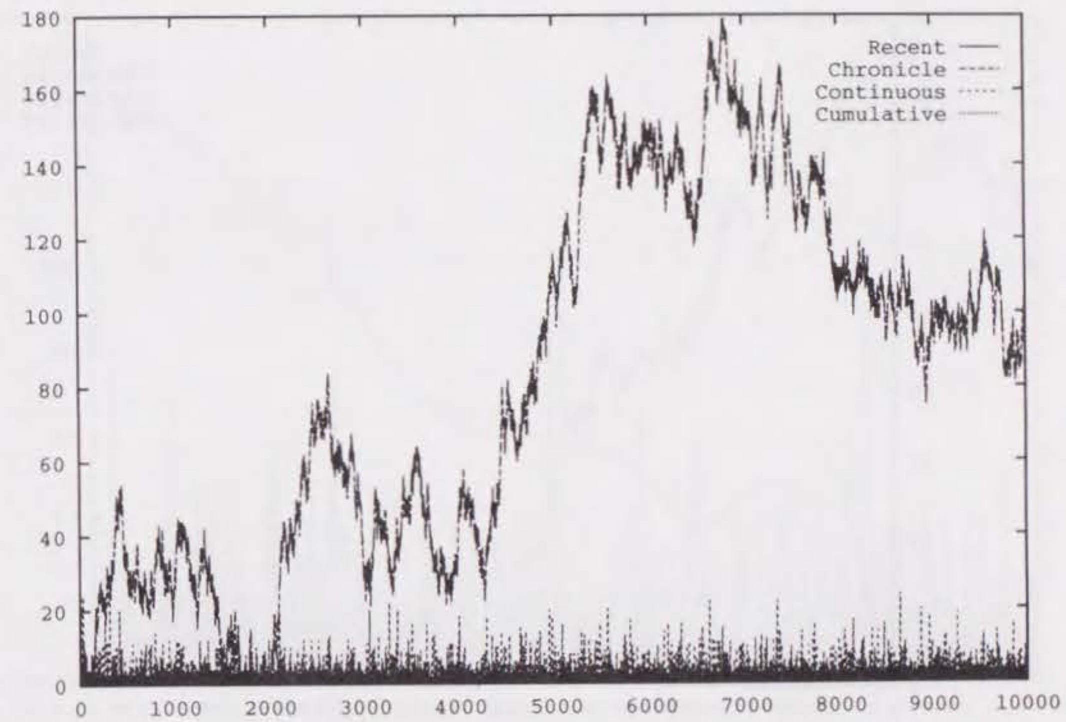

Figure 5.7: Memory requirement in four contexts.

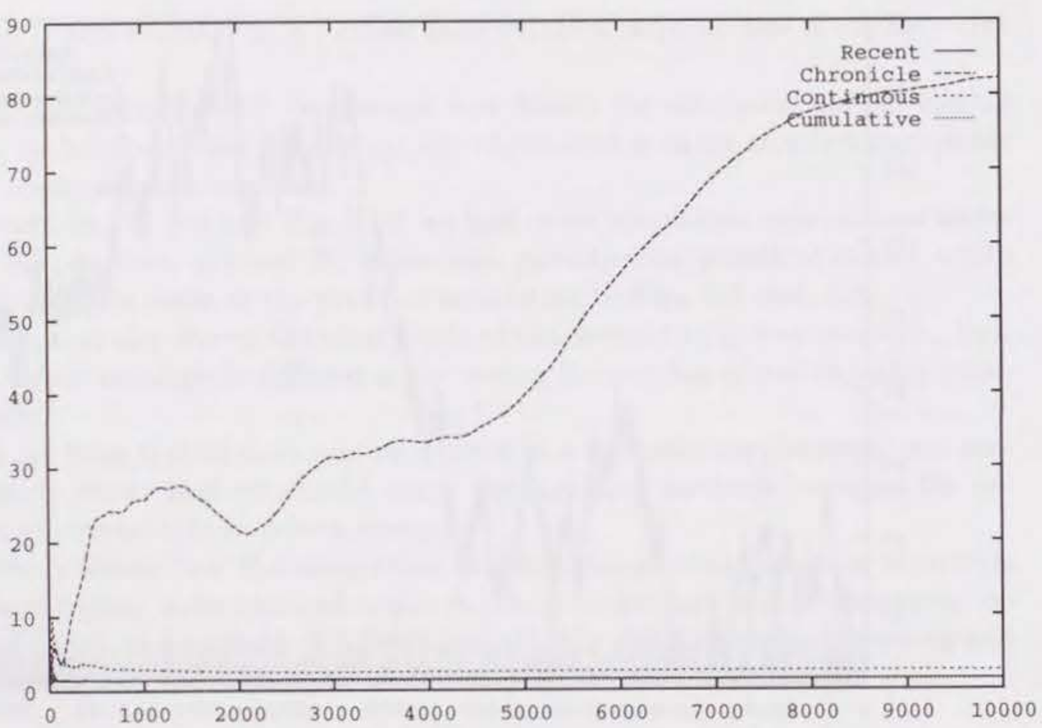

Figure 5.8: Average memory requirement in four contexts.

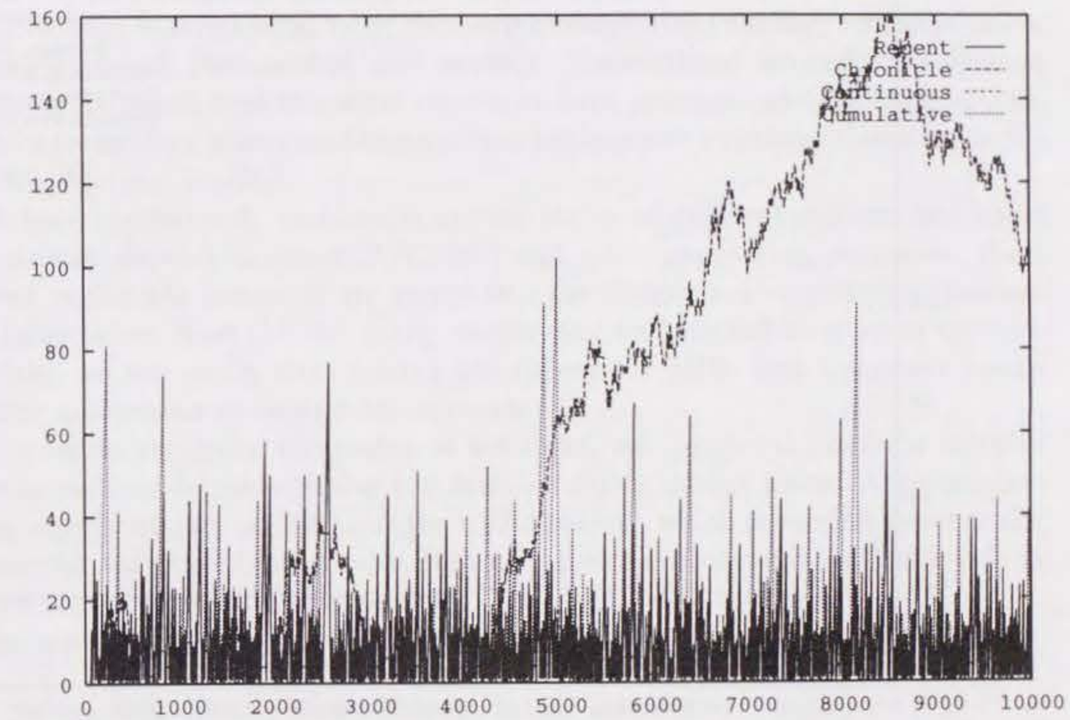

Figure 5.9: Memory requirement with many participating primitive events.

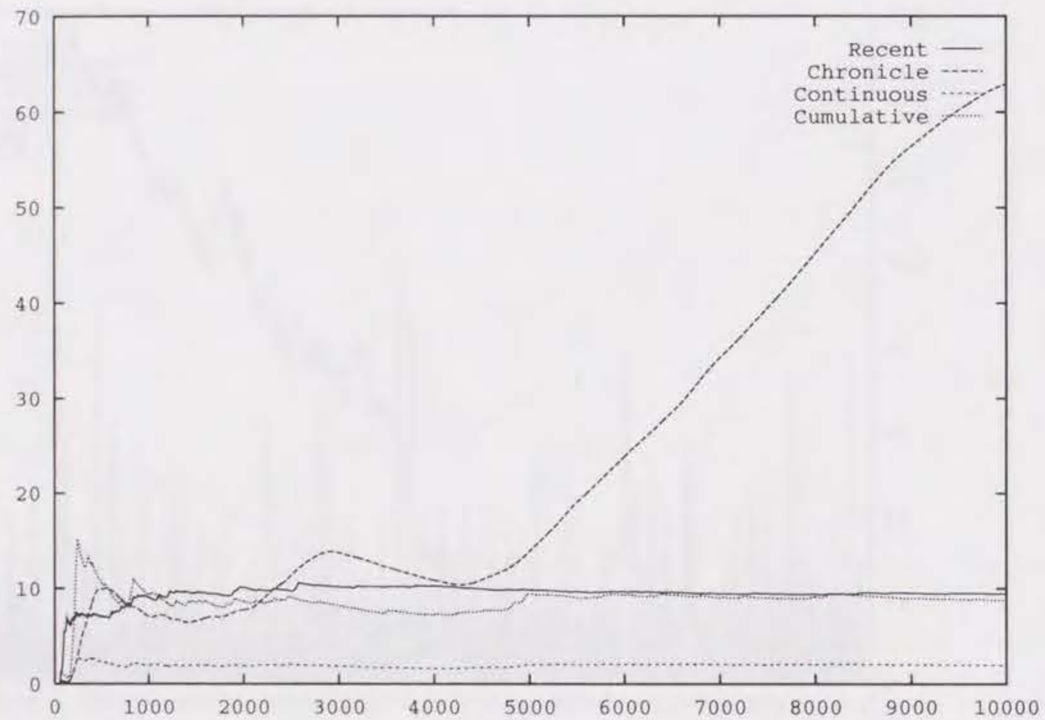

Figure 5.10: Average memory requirement with many participating primitive events.

5.6 Example of Mining Application Areas

In this section, we show one example from data mining application areas, such as a communication network, a production process, .etc. In these systems, huge volume of data is generated rapidly and continuously, and complex observed tuples or instances will be stored into management database in dynamic environment. It is very difficult to discover by human operators traffic patterns or troubles occurred in those systems from large volume of the management database, since the current status of the system are dynamically and quickly changing.

For example, in the interconnecting networks, lower abstract data stored in those databases may include *source address*, *destination address*, *packet length*, and *protocol type*, it is too difficult to discover rules by human operators. Moreover, there are several categories of complicated problems for network management, such as *performance management*, *error recovery management*, *topology reconfiguration*, *congestion control*, *flow control*, and *routing*. Conventional network management techniques are insufficient to resolve the above hard problem, advanced artificial intelligence technology is an attractive solution to the above problems[Covo89, Gerl91, Kawa92b, Morr91, Pan91].

We have continuously monitoring system status of different stations and layers using certain network protocols[RFC1067] and other monitoring programs. Huge observed tuples and instances are stored into the distributed or extended Management Information Base (MIBs), many events may be detected to activate systems. Therefore, we can apply data mining algorithms for MIBs and composite events detection mechanism to control the network.

In order to recognize the status of networks, our proposed attribute oriented induction method derives effective and flexible rules at mining phase. Applying data mining algorithms, we can find out the traffic pattern which is varying dynamically, and discover the other type of rules, such as the connectivity and the traffic volume between source and destination devices.

The typical examples of mining rules are as follows:

- The pattern of daily traffic is cyclic in our network.
- As the traffic load between your administrative network and mine becomes large, the traffic load of their network also increases.
- The connectivity between certain devices in their networks is good (or bad).
- Two domains share the same facility in outside domain.

5.7 Conclusion

In this chapter, we propose the sampling technique based on the occurrences of composite events instead of periodical sampling method. In order to develop biased sampling technique based on composite events/data, we compared the four semantics of composite events. Using several contexts, we evaluated the memory cost performance of the sampling method based on composite events detection in a dynamic environment. We had simulation study on the characteristics of composite events sampling technique in the point of required memory area during the execution time for mining queries. When we have typical data mining queries in a dynamic environment, our simulation study shows that we should adopt the sampling methods based on the occurrences of events/data except chronicle context. In the point of freshness of knowledge, recent context may be often meaningful.

Our study also shows that the integration of attribute oriented induction method with data sampling based on composite events and active database technology will substantially enhance the power and increase the flexibility of data and knowledge discovery and utilization in dynamic environments. As an illustrative example, we presented the basic idea to achieve the intelligent computer network management by application of active database systems and the technology of data mining.

Chapter 6

Conclusion

6.1 Summary of this Thesis

In this thesis, we have considered the intelligent management for stable information networks by using the feedback data gathered by various protocols on several communication layers[Stal93]. In many papers, the basic problems of instability or sensitivity phenomenon in contention type protocols has been pointed out under bursty or high load in the even one local network. Therefore, in the lower layers of communication protocols, various multiple access protocols have been proposed, developed and standardized in order to achieve the stable communication channel among many network equipments. Especially, in order to overcome this instability problem of the network, Tsybakov[Tsyb78] and Capetanakis[Cape79a] independently proposed an excellent protocols as collision resolution algorithms. Their protocols are based on tree algorithms or tree-based collision resolution algorithms, they effectively use the feedback information on the physical level. It is notable that tree-based collision resolution algorithms stabilize a contention-based communication system and guarantee the maximum throughput of the channel.

However, these kinds of protocols only utilize the feedback information in the lower level communication layer, it is too difficult to perform the global stability of the interconnected network systems. Especially, in the environment of multifarious protocols, it is important to gather and collect high level information in order to exchange the condition of the networks.

Therefore, the major objective of this dissertation is to propose and evaluate several new protocols in order to stabilize networks using multi protocols. In order to transmit various kinds of messages such as data, voice, or graphic images with different requirements for transmission, we focus on the stability control in both of local and wide area networks based on the lower and higher level feedback information.

First, we propose a CSMA/CD protocol employing the blocked access tree collision resolution algorithm as its back-off algorithm, and evaluate its performance. Our proposed TREE-CSMA/CD protocols is very effective for local area network environments, and also extended tree protocols as DTA-MR to utilize the feedback information to reserve transmission slots or frames effectively. However, the scale of interconnected networks has increased rapidly, and the specifications of communication equipments are quite various in the different networks. If it is possible to control the stability of network by lower protocols effectively, we could not unify and adopt same protocols in the standing points of several different network policies. Therefore we have to get much more informative feedback from the global network environment, such kinds of statistical information have been collected and stored into management information base. We have to derive high quality of rules, characteristics or knowledge from chaotic information storages as MIB in order to control and manage multifarious networks with various equipments. This problem is most important to construct and develop interconnected networks with various network equipments based on different protocols or strategies. In this thesis, we mentioned the techniques to control stability of networks by the feedback information from lower communication layers to higher ones.

First, we would like to review this thesis based on the chapter organization. In chapter 2, we proposed a CSMA/CD protocol employing the blocked access tree collision resolution algorithm as its back-off algorithm, and evaluated its performance. We have demonstrated the following three good properties of TREE-CSMA/CD. First, TREE-CSMA/CD protocol offers very high stability as compared with the CSMA/CD employing conventional back-off algorithms. In particular, no bistable behavior of the mean delay versus throughput performance is shown in the TREE-CSMA/CD and the FCFS discipline is realized because of the blocked access scheme. Second, the TREE-CSMA/CD realizes a similar system performance as that of the CSMA/CD with an optimal back-off algorithm (OPA) which ideally has the capability to recognize the number of terminals with transmitting packets. This gives a proof that the TREE-CSMA/CD employs a very efficient feedback mechanism of the channel information. Third, a robust scheme and a prioritized mechanism can be easily implemented utilizing the access mechanism of the TREE-CSMA/CD protocol.

In chapter 3, we proposed DTA-MR and investigated the priority mechanisms using the information from the sequence of transmitting time as well as the delay of transmitting time. As a result, it became clear that the DTA-MR is very flexible for employing priority mechanisms. That is, in addition to the internal priority functions of the original DTA-MR, the external priority mechanism is easily realized by adjusting the starting slot of conflict sub-sessions in the DTA-MR. By such a property, our proposed scheme is effective to transmit various kinds of messages such as *data*, *voice*, or *graphic images* with different requirements for transmission.

In chapter 4, we extended attribute-oriented induction algorithm for knowledge discovery in dynamic environments, in order to derive rules for the traffic distribution and patterns in the interconnected networks. First, a cluster of network data is collected by a data sampling technique, and stored into management information bases. An attribute-oriented induction technique is then applied which integrates the learning-from-examples methodology with set-oriented database operations and extracts generalized data from actual data in databases. Attribute-oriented induction and data sampling substantially reduce the computational complexity of a database learning process. The attribute-oriented induction algorithm with data sampling discovers three kinds of rules: characteristic rule, stable rule and evolution rule.

Our study shows that the integration of attribute-oriented induction algorithm with data sampling technique and active database technology will substantially enhance the power and increase the flexibility of data and knowledge discovery and utilization in dynamic environments. As an illustrative example, we studied the intelligent computer network management by application of the technology of knowledge discovery and active databases. By applying the proposed technique regarding to the data in a dynamic environment, the general rules which describe the traffic distribution and patterns can be summarized. Moreover, it facilitates topology reconfiguration of networks as well as the checking of the status of the machines and devices in the network. Moreover, using the technology of active database, generalized conditions can be evaluated and compared with the generalized rules for the control of the dynamic environment.

In chapter 5, we adopted the technology of active database to control the network systems in high level protocol layer, and we proposed the sampling technique based on the occurrences of composite events in the management information base. We also evaluated the memory cost performance of the sampling method based on composite events detection in several contexts.

First, we proposed the sampling technique based on the occurrences of composite events instead of periodical sampling method. In order to develop biased sampling technique based on composite events/data, we compared the four semantics of composite events. Using several contexts, we evaluated the memory cost performance of the sampling method based on composite events detection in a dynamic environment. We had simulation study on the characteristics of composite events sampling technique in the point of required memory area during the execution time for mining queries.

When we have typical data mining queries in a dynamic environment, our simulation study shows that we should adopt the sampling methods based on the occurrences of events/data except chronicle context. In the point of freshness of knowledge, recent context may be often meaningful.

Our study also shows that the integration of attribute oriented induction method with data sampling based on composite events and active database technology will substantially enhance the power and increase the flexibility of data and knowledge discovery and utilization in dynamic environments. As an illustrative example, we presented the basic idea to achieve the intelligent computer network management by application of active database systems and the technology of data mining.

Finally, the author would like to hope that the research in this thesis will be helpful for further study in this field.

6.2 Issues for Future Research

There are many issues which should be studied further.

To improve the system performance of the TREE-CSMA/CD protocol in chapter 2, it is possible to employ, e.g., the Improved Tree Algorithm (ITA) as its collision resolution algorithm for deleting redundant empty slots. However, in LAN systems, we can not expect a remarkable performance improvement by such techniques since the length of empty slot is very small as compared with that of successful packet transmission slot, though such improving techniques may make the protocol very complex. Considering its practicality, high performance, and desirable stability, the TREE-CSMA/CD is one of recommendable protocols in the CSMA/CD protocol family of the bus type LAN.

We have to discuss the following interesting future research topic regarding the DTA-MR in chapter 3. We assumed that all terminals have the homogeneous traffic load according to the mutually independent Poisson process. In practical systems, however, the traffic load may be non-homogeneous[Poly85] and it changes dynamically every moment. Thus, the study on the applicability of the DTA-MR to the system with non-homogeneous and dynamical traffic load changing will be a very important work for constructing autonomous decentralized systems.

In chapter 4 and 5, both data sampling and knowledge discovery processes can be triggered by active database rules. It is not clear how close interactions should be maintained between active database rules and knowledge discovery algorithms with data sampling. A tight management by active rules may restrict the possibilities of discovery of some unexpected events; however, a loose interaction may results in the discovery of a large number of uninteresting rules.

Furthermore, we are developing a prototype of integrated software environment for performance evaluation, which incorporates both the knowledge of queueing theory and simulation techniques[Kawa93]. In our present environment, we can analytically evaluate queueing networks with product form solutions to get average queue length and waiting time, and other performance measures. In order to make harmony of the different techniques of performance evaluation, we have to much more studies and experimental works[Ori96]. These researches include all areas of data visualization, data processing, knowledge filtering, sampling, data engineering, database mining techniques, machine learning, statistical pattern recognition, tools and applications. However, intelligent management will provide technical rich issues related to the research and applications of Artificial Intelligence techniques in data analysis across a variety of disciplines[Miur88, Kawa94a, Kawa96a]. We will have to try to examine the effectiveness of the techniques developed in this thesis and implement such intelligent mechanisms in a real network management systems.

Appendix A

Upper and Lower Bounds of eq.(2.7)

By using the Kronecker's delta δ_{ij} defined by 1 if $i = j$ and 0, otherwise, we can give the following inequality concerning the upper bound of eq.(2.7) which is satisfied for $k(\geq 0)$.

$$M(k) \leq \alpha_u(m)k - 1 + \sum_{i=0}^{m-1} \delta_{ik}(M(k) - \alpha_u(m)k + 1) \tag{A.1}$$

Obviously, if $k \geq m$, $\delta_{ik} = 0$ for $i = 0, 1, \cdots, m-1$, and thus eq.(A.1) coincides with eq.(2.7). If $k < m$, the right hand side is equal to $M(k)$. Furthermore, we have the following equation.

$$\begin{aligned} \sum_{i=0}^{k-1} iP(k,i) &= \sum_{i=0}^{k} iP(k,i) - kP(k,k) \\ &= \frac{k}{2} - k2^{-k} \end{aligned} \tag{A.2}$$

Substituting eq.(A.1) and eq.(A.2) into $M(i)$ of the right hand side of eq.(2.6), we can get

$$M(k) \leq \alpha_u(m)k - 1 + \left[\frac{2\left\{ \sum_{i=0}^{m-1} (M(i) - \alpha_u(m)i + 1) \cdot P(k,i) \right\}}{(1 - 2^{-k+1})} \right]. \tag{A.3}$$

We can easily show the following inequality concerning a part of the right hand side of eq.(A.3).

$$\sum_{i=0}^{m-1} (M(i) - \alpha_u(m)i + 1)P(k,i) \leq 0 \qquad (k \geq m),$$

and we can get the following inequality.

$$\alpha_u(m) \sum_{i=0}^{m-1} iP(k,i) \geq \sum_{i=0}^{m-1} (M(i) + 1)P(k,i) \qquad (k \geq m)$$

Consequently, we can obtain the following $\alpha_u(m)$ which gives the upper bound of $M(k)$.

$$\alpha_u(m) = \sup_{k\geq m}\left[\sum_{i=0}^{m-1}\binom{k}{i}(M(i)+1)/\sum_{i=0}^{m-1}\binom{k}{i}i\right] \tag{A.4}$$

In a manner similar to the derivation of $\alpha_u(m)$, we can provide the following $\alpha_\ell(m)$ which gives the lower bound of $M(k)$.

$$\alpha_\ell(m) = \inf_{k\geq m}\left[\sum_{i=0}^{m-1}\binom{k}{i}(M(i)+1)/\sum_{i=0}^{m-1}\binom{k}{i}i\right]. \tag{A.5}$$

Appendix B

Evaluation of $E(Y_d)$ and $E(Y_a)$

We can obtain the following inequality from eq.(2.20).

$$\begin{aligned} P(X_d = 1|Y_a = M) &= \lambda M \exp(-\lambda M) \\ &= \lambda M P(X_d = 0|Y_a = M) \\ &\geq \lambda P(X_d = 0|Y_a = M), \end{aligned}$$

this means $P(X_d = 1) \geq \lambda P(X_d = 0)$. Next, multiplying both sides of equation $P(X_d = 0|Y_a = M) = \exp(-\lambda M)$ by $P(Y_a = M)$, and summing over M,and further applying the Jensen's inequality to the obtained equation, we can get $P(X_d = 0) \geq \exp(\lambda E(Y_a))$. Furthermore, we can easily show the following inequality, $P(X_d = 2) \leq 1 - P(X_d = 0) - P(X_d = 1)$. By applying these three relations as well as eq.(2.26) to the equation which is obtained by multiplying both sides of eq.(2.31) by $P(X_d = k)$ and summing over k, we can get eq.(2.35) and eq.(2.36).

Next, since $E(Y_\infty^2)$ satisfies the following equation:

$$E(Y_\infty^2) = \sum_{k=0}^{\infty} E(Y^2|X = k)P(X = k) = \sum_{k=0}^{\infty} S_k \pi_k,$$

we can obtain the following inequality by multiplying both sides of eq.(2.34) by π_k and summing over k.

$$E(Y_\infty^2) \geq UE(X_\infty^2) + VE(X_\infty) + W - 3\pi_0 - X\pi_1 + Y\pi_2$$

Moreover, applying the above equation to the next equation:

$$E(X_{i+1}|Y_i = M) = \lambda M + (\lambda M)^2,$$

we can get

$$E(X_\infty^2) = E(X_\infty) + \lambda^2 E(Y_\infty^2).$$

Further, by the equation:

$$E(Y_\infty) = \sum_{k=0}^{\infty} M(k)\pi_k,$$

we can give the following inequality:

$$E(Y_\infty) \geq (L+3)\pi_1.$$

From the relations obtained above, we can provide the following lower bound of $E(Y_a)$.

$$E(Y_a) \geq \frac{(U+V)\lambda + \dfrac{W - 3\pi_0 - X\pi_1 + Y\pi_2}{E(Y_\infty)}}{1 - U\lambda^2}$$

Finally, using $\pi_0 = 1$ and $\pi_2 = 0$, we can obtain eq.(2.37) which gives the lower bound of $E(Y_a)$. In a manner similar to the above process, we can get eq.(2.38) which gives the upper bound of $E(Y_a)$.

Bibliography

[Abra70] N. Abramson, "The ALOHA System – Another Alternative for Computer Communication," in AFIPS Conference Proc. Fall Joint Comput. Conference, pp.281–285, 1970.

[ANSI802.3] ANSI/IEEE std 802.3, "ANSI/IEEE Standard for LANs: CSMA/CD Access Method and Physical Layer Specifications," IEEE, Inc. and John Wiley & Sons, Inc., 1985.

[Atki90] M. Atkinson, F. Bancilhon, D. DeWitt, K. Dittrich, D. Maier, and S. Zdonik, "The Object-Oriented Database Systems Manifesto," W. Kim, J.-M. Nicolas, and S. Nishio (eds.), Deductive and Object-Oriented Databases, pp.223–240, Elsevier Science, 1990.

[Beer91] C. Beeri and T. Milo, "A Model for Active Object Oriented Database," Proc. of the 17th International Conference on Very Large Data Bases, Barcelona, Spain, pp.337–349, Sept. 1991.

[Cai91] Y. Cai, N. Cercone, and J. Han. "Attribute-Oriented Induction in Relational Databases," G. Piatetsky-Shapiro and W. J. Frawley (eds.), Knowledge Discovery in Databases, pp.213–228, AAAI/MIT Press, 1991.

[Cape79a] J.I. Capetanakis, "Tree Algorithm for Packet Broadcast Channels," IEEE Transactions on Information Theory, Vol.IT-25, No.5, pp.505–515, 1979.

[Cape79b] J.I. Capetanakis, "Generalized TDMA: The Multi-Accessing Tree Protocol," IEEE Transactions on Communications, Vol.COM-27, No.10, pp.1476–1484, 1979.

[RFC1067] J. Case, M. Fedor, M. Schoffstall and J. Davin, "The Simple Network Management Protocol," RFC 1067, August 1988.

[Chak94] S. Chakravarthy, V. Krishnaprasad, E. Anwar and S.-K. Kim, "Composite Events for Active Databases: Semantics, Contexts and Detection," Proc. of the 20th International Conference on Very Large Data Bases, Santiago, Chile, pp.606–617, 1994.

[Covo89] A. A. Covo, T. M. Moruzzi and E. D. Peterson, "AI-assisted Telecommunication Network Management," Proc. 1989 IEEE GLOBECOM, Dallas, pp.487–491, 1989.

[Daya88] U. Dayal, B. Blaustein, A. Buchmann, U .Chakravarthy, M. Hsu, R. Ladin, D. McCarthy, A. Rosenthal, S. Sarin, M. J. Carey, M. Livny and R. Jauhari, "The HiPAC Project: Combining Active Databases and Timing Constrains," ACM-SIGMOD Record 17, pp.51–70, March 1988.

[VLDB95] U. Dayal, P. M. .D. Gray and S. Nishio (eds.): "Proceedings of the 21st International Conference on Very Large Data Bases," Zurich, Switzerland, 1995.

[Diet83] T. G. Dietterich and R. S. Michalski, "A Comparative Review of Selected Methods for Learning from Examples," Michalski et. al. (eds.), Machine Learning: An Artificial Intelligence Approach, Vol. 1, pp.41–82. Morgan Kaufmann, 1983.

[Fayo77] G. Fayolle, E. Gelenbe and J. Labetoulle, "Stability and Optimal Control of the Packet Switching Broadcast Channel," J.ACM, Vol.24, No.3, pp.375–386, 1977.

[Fish87] D. Fisher, "Improving Inference through Conceptual Clustering," Proc. 1987 AAAI Conference, Seattle, Washington, pp.461–465, July 1987.

[Fraw91] W.J. Frawley, G. Piatetsky-Shapiro, and C.J. Matheus, "Knowledge Discovery in Databases: An Overview," G. Piatetsky-Shapiro and W.J. Frawley, (eds.), Knowledge Discovery in Databases, pp.1–27, AAAI/MIT Press, 1991.

[Geha92] N. H. Gehani, H. V. Jagadish and O. Shmueli, "Composite Event Specification in Active Databases: Model & Implementation," Proc. of the 18th International Conference on Very Large Data Bases, Vancouver, Canada, pp.327–338, August 1992.

[Geor83] L. Georgiadis and P. Papantoni-Kazakos, "A Collision Resolution Protocol for Random Access Channels with Energy Detectors," IEEE Transactions on Communications, Vol.COM-30, No.11, pp.2413–2420, 1982.

[Geor86] M. Georgiouspoulos, L. Merakos and P. Papantoni Kazakos, "High Performance Asynchronous Limited Sensing Algorithms for CSMA and CSMA-CD Channels," in Local Area & Multiple Access Networks, ed. L.Pickholtz, pp.185–214, Computer Science Press, Rockville, Maryland, 1986.

[Gerl91] M. Gerla and Y. Lin, "Network/Intelligence: An Experiment on Interconnected LANs," G. Piatetsky-Shapiro (eds.), Proc. of 1991 AAAI Workshop on Knowledge Discovery in Databases, Anaheim, pp.254–260, July 1991.

[Good88] J. Goodman, A.G. Greenberg, N. Madras, and P. March, "Stability of Binary Exponential Backoff," J.ACM, Vol.35, No.3, pp.579–602, 1988.

[Han91] J. Han, Y. Cai and N. Cercone, "Concept-Based Data Classification in Relational Databases," G. Piatetsky-Shapiro (eds.), Proc. of 1991 AAAI Workshop on Knowledge Discovery in Databases, Anaheim, pp.77–94, July 1991.

[Han92] J. Han, Y. Cai, and N. Cercone, "Knowledge Discovery in Databases: An Attribute-Oriented Approach," Proc. of the 18th International Conference on Very Large Data Bases, Vancouver, Canada, pp.547–559, August 1992.

[Han93] J. Han, S. Nishio, and H. Kawano, "Knowledge Discovery in Object-Oriented and Active Databases," Proc. of International Conference on Building and Sharing of Very Large-Scale Knowledge Bases'93, pp.205–214, Dec. 1993.

[Han94] J. Han and Y. Fu, "Dynamic Generation and Refinement of Concept Hierarchies for Knowledge Discovery in Databases," Proc. of 1994 AAAI Workshop on Knowledge Discovery in Databases, Seattle, WA, pp.157–168, 1994.

[Haus87] D. Haussler, "Bias, Version Spaces and Valiant's Learning Framework," Proc. 4th International Workshop on Machine Learning, Irvine, pp.324–336, 1987.

[Haye78] J. F. Hayes, "An Adaptive Technique for Local Distribution," IEEE Transactions on Communications, Vol.COM-26, No.8, pp.1178–1186, 1978.

[Hofr84] M. Hofri, "Stack Algorithms for Collision-Detecting Channels and Their Analysis: A limited survey," in: F. Baccelli and G. Fayolle (eds.), Lecture Notes in Control and Information Sciences 60 (Proc. International Seminar on Modelling and Performance Evaluation Methodology, INRIA, France 1983), Springer-Verlag, Berlin, pp.71–88, 1984.

[Hols94] M. Holsheimer and A. Siebes, "Data Mining – The Search for Knowledge in Databases," CWI Technical Report CS-R9406, 1994.

[Huan85] J. C. Huang and T. Berger, "Delay Analysis of Interval Searching Contention Resolution Algorithm," IEEE Transactions on Information Theory, Vol.IT-31, No.2, pp.264–273, 1985.

[Iwas88] Y. Iwasaki and I. Bhandari, "Formal Basis for Commonsense Abstraction of Dynamic Systems," AAAI-88, pp.307–312, August 1988.

[Kawa87] H. Kawano, S. Nishio and T. Hasegawa, "Tree Algorithms with Message Reservation – An Efficient Use of Information from Success Packet –," Proc. 1985 IEEE GLOBECOM., pp.15.4.1–15.4.5, 1987.

[Kawa88a] H. Kawano, S. Nishio and T. Hasegawa, "CSMA/CD with Tree Algorithms," Transactions of the Institute of Electronics Information and Communication Engineers (IEICE), Vol. J71-B, No.2, pp.138–149, 1988 (in Japanese).

[Kawa88b] H. Kawano, S. Nishio and T. Hasegawa, "Tree Collision Resolution Algorithms Using Information from Successful Transmission Packets," Proc. of IEEE International Symposium on Information Theory, p.182, Kobe, Japan, June 1988.

[Kawa91] H. Kawano, K. Sonoo, S. Nishio and T. Hasegawa, "Accuracy Evaluation of Rules Derived from Sample Data in VLKD," Conference Record, ORSA/TIMS Joint National Meeting, Anaheim, California, p.144, Nov. 1991, [Kawa92a] H. Kawano, S. Nishio, and T. Hasegawa, "Deterministic Tree Type Algorithm with Reservation Mechanism," Electronic Communication Japan Vol.76, No.3, pp.55–65, 1993. Translated from Transactions of the Institute of Electronics Information and Communication Engineers (IEICE), Vol. J75-B-I, No.3, pp.156–164, 1992 (in Japanese).

[Kawa92b] H. Kawano, S. Nishio and T. Hasegawa, "Knowledge Acquisition in Communication Networks," IEEE Region 10 Conference, Tencon 92, Australia, pp.881–885, Nov. 1992.

[Kawa93] H. Kawano, Y. Akamatsu, F. Ukai, Y. Takahashi and T. Hasegawa,: Software Environment for Hybrid Performance Evaluation Tool, Proc. of IEEE Pacific Rim Conference on Communications, Computers and Signal Processing, Canada, Victoria, pp.532–535, 1993.

[Kawa94a] H. Kawano, "Knowledge Discovery in Databases," Journal of the Society of Instrument and Control Engineers, Vol.33, No.6, pp.520, 1994 (in Japanese).

[Kawa94b] H. Kawano S. Nishio, J. Han and T. Hasegawa, "How Does Knowledge Discovery Cooperate with Active Database Techniques in Controlling Dynamic Environment?," Proc. 5th International Conference on Database and Expert Systems Applications (DEXA'94), Athens, Greece, pp.370–379, September 1994.

[Kawa95a] H. Kawano, S. Nishio, J. Han, "Technology of Knowledge Discovery in Databases," Journal of Japanese Society for Artificial Intelligence, Vol.10, No.1, pp.38–44, 1995 (in Japanese).

[Kawa95b] H. Kawano and T. Hasegawa, "Data Mining Technology for Network Management," INFORMS International Singapore, Singapore, p.36, 1995.

[Kawa95c] H. Kawano and T. Hasegawa, "Data Mining with Composite Events Based Sampling in a Dynamic Environment," Proc. of XII International Conference on Systems Science, Poland, pp.141–158, 1995.

[Kawa96a] H. Kawano and T. Hasegawa, "Data Mining Algorithms with Entropy-based Cost Functions," Proc. of Eleventh International Conference on Systems Engineering, Las Vegas, pp.957–962, 1996.

[Kawa96b] H. Kawano, S. Nishio, J. Han and T. Hasegawa, "Integration of Knowledge Discovery and Active Database Technologies," Journal of Japanese Society for Artificial Intelligence, Vol.11, 1996 to appear (in Japanese).

[Kawa96c] H. Kawano and T. Hasegawa, "Data Mining with Composite Events Based Sampling in a Dynamic Environment," Systems Science, No.3, Vol.22, 1996 to appear.

[Klei75] L. Kleinrock, "Queueing systems, volume I: Theory," John Wiley & Sons, New York, 1975.

[Klei75b] L. Kleinrock and F. A. Tobagi, "Packet Switching in Radio Channel: Part I – Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics," IEEE Transactions on Communications, Vol.COM-23, No.12, pp.1400–1416, 1975.

[Lang87] P. Langley, H.A. Simon, G.L. Bradshaw and J.M. Żytkow, "Scientific Discovery: Computational Explorations of the Creative Processes," MIT Press, 1987.

[Mass80] J. L. Massey, "Collision-Resolution Algorithms and Random-Access Communications," Technical Report UCLA-ENG-8016, School of Engineering and Applied Science, University of California, Los Angeles, April 1980.

[Math85] P. Mathys, and P. Flajolet, "Q-ary Collision Resolution Algorithms in Random-Access Systems with Free or Blocked Channel Access," IEEE Transactions on Information Theory, Vol.IT-31, No.2, pp.217–243, 1985.

[McCa89] D. R. McCarthy and U. Dayal, "The Architecture of an Active Database Management System," Proc. 1989 ACM SIGMOD International Conference on Management of Data, Portland, OR, pp.215–24, June 1989.

[Medi83] J. S. Meditch, and C. T. A. Lea, "Stability and Optimization of the CSMA and CSMA/CD Channels," IEEE Transactions on Communications, COM-31, No.6, pp.763–773, 1983.

[Mera83] L. Merakos and D. Kazakos, "Multiaccess of a Slotted Channel using a Control Mini-Slot," Proc. of 1983 IEEE International Conference on Communication, pp.C5.3.1–C5.3.6, 1983.

[Mich83] R. Michalski, "A Theory and Methodology of Inductive Learning," Michalski et. al. (eds.), Machine Learning: An Artificial Intelligence Approach, Vol.1, Morgan Kaufmann, 1983.

[Mich91] J. Michael, M. J. Carey, R. Jauhari and M. Livny, "On Transaction Boundaries in Active Databases: a Performance Perspective," IEEE Transactions on Knowledge Data Engineering, Vol.3, No.3, pp.320–336, September 1991.

[Miur88] F. Miura, H. Kawano, S. Nishio and T. Hasegawa, "Structure and Performance of the Stream Processor Organized by Bus-Connected Filtering Processors," Transactions of the Institute of Electronics Information and Communication Engineers (IEICE), Vol. J71-D, No.8, pp.1467–1472, 1988 (in Japanese).

[Moll83] M. L. Molle, "Asynchronous Multiple Access Tree Algorithms," Proc. ACM SIG-COMM 83 Symposium on Communication Architecture and Protocols, pp.214–218, 1983.

[Morr91] R.J.T. Morris and B. Samadi, "Neural Networks in Communications: Admission Control and Switch Control," Proc. of International Conference on Communication, Denver, pp.648–654, 1991.

[Mose85] J. Mosely and P. Humblet, "A Class of Efficient Contention Resolution Algorithms for Multiple Access Channels," IEEE Transactions on Communications, Vol.COM-33, No.2, pp.145–151, 1985.

[Muro85] S. Muro, Y. Oie and T. Hasegawa, "A Proof of Channel Stability of d-ary Symmetrical Tree Algorithms," Proc. of International Conference on Modelling Techniques and Tools for Performance Analysis, AFCET, France, pp.349–364, 1985.

[Muro86a] S. Muro, Y. Oie, and T. Hasegawa, "Tree Collision Resolution Algorithms in Multiple Access Communication Protocol," Journal of Information Processing, Vol.27, No.5, pp.508–522, May 1986 (in Japanese).

[Muro86b] S. Muro, Y .Oie, H. Kawano, and T. Hasegawa, "Tree Algorithms for Random Access Channels in Local Area Networks," Proc. of International Conference on Communication, Toronto, Canada, pp.620–624, June 1986.

[Nish93] S. Nishio, H. Kawano and J. Han, "Knowledge Discovery in Object-Oriented Databases: The First Step," Proc. of AAAI-93 Workshop on Knowledge Discovery in Databases, pp.186–198, July 1993.

[Nomu84] Y. Nomura, H. Okada and Y. Nakanishi, "Performance Evaluation of CSMA/CD with Various Back-Off Protocols," the Transactions of the Institute of Electronics and Communication Engineers of Japan, Vol.J67-D, No.2, pp.184–191, February 1984 (in Japanese).

[Oie85] Y. Oie, S. Muro and T. Hasegawa, "Tree Algorithm for Reservation Multiple Access," Proc. of IEEE International Conference on Communication, pp.3.5.1–3.5.5, 1985.

[Oie86] Y. Oie, "Studies on Collision Resolution Algorithms in Communication Systems," Ph.D Thesis, Dept. of Applied Math. and Physics, Faculty of Engineering, Kyoto University, Aug. 1986.

[Ori96] K. Ori, H. Kawano, Y. Takahashi and T. Hasegawa, "An Approach for Network Diagnosis Based on Performance Analysis," Proc. of 4th International Conference on Telecommunication Systems Modelling and Analysis, Nashville, pp24–32, 1996.

[Pan91] H. Pan and I. Wang, "The Bandwidth Allocation of ATM through Genetic Algorithm," Proc. 1991 IEEE GLOBECOM, Phoenix, pp.125–129, 1991.

[Pars89] K. Parsaye, M. Chignel, S. Khoshafian and H. Wong H, "Intelligent Databases," John Wiley & Sons, Inc., 1989.

[Piat89] G. Piatetsky-Shapiro, "Discovery and Analysis of Strong Rules in Databases," Proc. of Advanced Database System Symposium '89, Kyoto, Japan, pp.135–142, December 1989.

[Piat91a] G. Piatetsky-Shapiro and W.J. Frawley, Knowledge Discovery in Databases, AAAI/MIT Press, 1991.

[Piat91b] G. Piatetsky-Shapiro, "Discovery, Analysis, and Presentation of Strong Rules," G. Piatetsky-Shapiro and W. J. Frawley (eds.), Knowledge Discovery in Data bases, AAAI/MIT Press, pp.229–248, 1991.

[Piat91c] G. Piatetsky-Shapiro and C.J. Matheus, "Knowledge Discovery Workbench: An Exploratory Environment for Discovery in Business Databases," G. Piatetsky-Shapiro (eds.), Proc. of 1991 AAAI Workshop on Knowledge Discovery in Databases, Anaheim, pp.11–24, July 1991.

[Pipp81] N. Pippenger, "Bounds on Performance of Protocols for a Multiple-Access Broadcast Channel," IEEE Transactions on Information Theory, Vol.IT-27, No.2, pp.145–151, 1981.

[Poly85] G. C. Polyzos, M. L. Molle and A. N. Venetsanopoulos, "Delay Analysis of Tree Conflict Resolution Algorithms: the Non-Homogeneous Case," Proc. 1985 IEEE GLOBECOM, pp.48.3.1.–48.3.6, 1985.

[Poly93] G. C. Polyzos and M. L. Molle, "A Queueing Theoretic Approach to the Delay Analysis for the FCFS 0.487 Conflict Resolution Algorithm," IEEE Transactions on Information Theory, Vol.39, No.6, pp.1887–1906, 1993.

[Shim86] N. Shima, S. Muro and T. Hasegawa, "Performance Evaluation of a Deterministic Tree Collision Resolution Algorithm," Proc. of International Computer Symposium, pp.1525–1534, 1986.

[Silb91] A. Silberschatz, M. Stonebraker, and J. D. Ullman, "Database Systems: Achievements and Opportunities," Communication of ACM, Vol. 34, pp.94–109, 1991.

[Sono91] K. Sonoo, H. Kawano, S. Nishio and T. Hasegawa, "Accuracy Evaluation of Rules Derived from Sample Data in VLKD," Proc. of the 5th Annual Conference of JSAI, pp.181–184, 1991 (In Japanese).

[Stal93] W. Stallings, "SNMP, SNMPv2, and CMIP: the Practical Guide to Network Management Standards," Addison-Wesley, 1993.

[Ston91] M. Stonebraker and G. Kemnitz, "The POSTGRES Next-Generation Database Management System," Communication of ACM, Vol.34, pp.78–93, 1991.

[Ston93] M. Stonebraker, R. Agrawal, U. Dayal, E. Neuhold and A. Reuter, "DBMS Research at a Crossroads: The Vienna Update," Proc. of the 19th International Conference on Very Large Data Bases, Dublin, Ireland, pp. 688–692, Aug. 1993.

[Tane81] A. S. Tanenbaum, "Computer Networks," Prentice-Hall, Inc., 1981.

[Toba76] F. A. Tobagi, and L. Kleinrock, "Packet Switching in Radio Channels: Part III-Polling and (Dynamic) Split Channel Reservation Multiple Access"' IEEE Transactions on Communications, Vol.COM-24, No.8, pp.832–845, 1976.

[Toba77] F. A. Tobagi, and L. Kleinrock, "Packet Switching in Radio Channels: Part IV-Stability Considerations and Dynamic Control in Carrier Sense Multiple Access," IEEE Transactions on Communications, Vol.COM-25, No.10, pp.1103–1120, 1977.

[Toba80] F. A. Tobagi, "Multiaccess Protocols in Packet Communication Systems," IEEE Transactions on Communications, Vol.COM-28, No. 4, pp.468–488, 1980.

[Tows87] T. Towsley and P. O. Vales, "Announced Arrival Random Access Protocols," IEEE Transactions on Communications, Vol.COM-35, No.5, pp.513–521, 1987.

[Tsyb78] B. S. Tsybakov, and V. A. Mikhailov, "Free Synchronous Packet Access in a Broadcast Channel with Feedback," Problems of Information Transmission, Vol. 14, No. 4, pp.259–280, 1978. Translated from Prolemy Peredachi Informatsii, Vol. 14, No. 4, pp.32–59, 1978 (in Russian).

[Tsyb80a] B. S. Tsybakov and V. A. Mikhailov, "Random Multiple Packet Access: Part-and-Try Algorithm," Problem of Information Transmission, Vol. 16, No.4, pp.305–317, 1980. Translated from Prolemy Peredachi Informatsii, Vol.16, No.4, pp.65–79, 1980 (in Russian).

[Tsyb80b] B. S. Tsybakov and M. A. Berkovskii, "Multiple Access with Reservation, " Prob. Inform. Transmission, Plenum Publishing Company, New York, pp.35–54, 1980; translated from Problemy Peredachi Informatsii, Vol.16, No.1, pp.50–76, 1980 (in Russian).

[Tsyb82] B. S. Tsybakov and V. A. Mikhailov, "Allowance for Packet Propagation Time in Random Multiple Access," Prob. Inform. Transmission, Plenum Publishing Company, New York, pp.131–134, 1982; translated from Problemy Peredachi Informatsii, Vol.17, No.2, pp.75–78, 1981 (in Russian).

[Tsyb87] B. S. Tsybakov and N. B. Likhanov, "Upper Bound on the Capacity of a Random Multiple Access System, " Problems of Information Transmission, Vol.23, No. 3, pp.224–236, 1987. Translated from Prolemy Peredachi Informatsii, Vol.23, No.3, pp.64–78, 1987 (in Russian).

[Ullm88] J. D. Ullman, "Principles of Database and Knowledge-Base Systems, Vol. 1," Computer Science Press, 1988.

[Vite79] A. J. Viterbi, and J.K. Omura, "Principle of Digital Communication and Coding," pp.40–42, McGraw-Hill, New York, 1979.

[Wido92] J. Widom, "Active Database Rule Systems," 3rd International Conference on Extending Database Technology, Tutorial 7, Vienna, Austria, March 1992.